PUBLIC ROADS

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UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

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THE PUBLICATION OF RESEARCH[1]

By E. W. ALLEN, Chief, Office of Experiment Stations, United States Department of Agriculture

THE ultimate aim of research is publication. It may be deferred, but it is due eventually if the research has been successful. To some this final task, like the end of a poor cigar, is often very bitter. But in research the end is even more important than the beginning, and quite as deserving of being well done as any other part of the work.

The idea that in writing a paper "anything will do," and that it is a weakness and a waste of time to be fussy about it, will rarely bring a creditable printed report or stamp the author as a painstaking investigator. Writing is, to some extent, a special aptitude or acquirement, and those with whom it is not a native ability can do much to improve it by practice and by taking pains. It is especially important for the scientist, because it is his means of communication and, to a large extent, of his influence. Hence his attitude toward the task should be right.

Publication is a serious matter because of the permanence of the record. A printed paper can not be recalled or retracted as the spoken work can; it stands for all time. Of course, a statement may be explained or modified after it has been published, but it is difficult to reach all readers of the original, and the correction may be overlooked in future citation.

For us in the Department of Agriculture, which stands so close to the public on the one hand, and to various branches of science on the other, the obligation to publish the results of investigation in suitable form is no less heavy than that of making the work itself exact in method and deduction. The manner in which this is done will reflect not only upon the individual worker but upon his organization and the department as a whole.

Unfortunately, much scientific writing of the present time is loose and indefinite in its expression, verbose often to the point of being tedious, and out of harmony with the ordered, exact, and logical nature of science itself. It is the subject of much unfavorable comment not only by the press but by other classes of writers. Sir James Barrie recently remarked that "The man of science appears to be the only man who does not know how to say it." Apropos of certain "diffuse" and "overloaded" papers presented at the British Association a few years ago, the London Times pointedly remarked that "Science should not disdain the art of presentation." The publications of the department and the experiment stations have long been popular subjects for newspaper gibes, sometimes partially merited and frequently a reflection on the reporter for his lack of understanding or for being so far behind the times.

While we can never hope wholly to escape such comment, we can take away such ground for it as lies in faulty writing or failure to adapt the text to the audience addressed. For it is all too true that scientific men are often unsuccessful writers, not only for popular reading but for their fellow specialists. This is partly because their training has not been in that line and their minds have been schooled to analytical habits, and partly because they are not willing to take sufficient pains or exercise critical judgment in selecting and presenting their material.

The purpose of writing is not only to express ideas, but to communicate them to others. Science is not inherently dull, heavy, and hard to comprehend; it is essentially fascinating, understandable, and full of charm. It is simple, after it has been worked out, and is capable of being stated in concise terms easily understood. But to succeed in conveying ideas correctly and in a readable way requires considerable effort on the part of most of us. It calls for time to do it well. It is just as important as making more experiments, although the worker may not like it as well, and is quite as worthy of his best effort. He should take care not to overestimate his ability to dash off a research paper at odd times.

CLEAR THINKING MAKES CLEAR WRITING

The aim in publishing research, as well as in carrying it on, is to leave the field clearer than you found it. If that can not be done it is doubtful whether a scientific paper is justified. There can not be clear writing without clear thinking, and when one learns to write clearly he will in the process learn to think clearly. Indeed, it may be doubted whether thought and its expression can be separated. Vagueness or turbidity of language usually indicates similar qualities in the thinking. The attempt to express a matter clearly in writing thus helps in the process of clear thinking. Bacon wrote that "reading maketh a full man, conference a ready man, and writing an exact man."

Since the object of writing is to communicate information, the writer may well give special attention to being intelligible. The audience addressed needs to be kept in mind and the language adapted to the reader. Sir Clifford Allbutt lays down the good rule to "take pains with yourself first, then with your reader"; and says further: "A writer who writes to convince and not merely to see his name in print must learn to lay his mind alongside that of his reader."

In other words, it is necessary to understand and keep in mind the point of view of those it is desired to reach, the mental background with which the new facts must be harmonized. The writer must know how to present his facts and arguments so that they will fit into the reader's experience and what he already knows. The reader may know something about the subject, but he doesn't know the point of view from which it was taken up, the purpose, and the reasoning, or how the work further clarifies the subject, unless these things are presented in their proper setting.

Clearness is absolutely essential in technical writing. It is not enough to use language that may be understood—it is necessary to use language that can not be misunderstood. Whether we agree with the author or not, we should never be in doubt as to what he means.

One of the first requisites to clearness of expression is mastery of the language—not in the mere passive sense of avoiding errors, but positively, as a flexible medium for the exact, unmistakable expression of thought. The choice of words, the order in which they are arranged, the sequence of clauses composing sentences, and, finally, the arrangement of sentences in a paragraph, are important features in effecting clearness.

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[1] A lecture delivered before the class in "The Nature and Method of Research," of the graduate school, Department of Agriculture.

Words are the vehicle of language. They are to impart ideas; hence care needs to be exercised in their choice. There are fine shades of meaning to be observed. The use of the right word will save considerable explanation and thus assist brevity. "The wrong word derails the thought; the needless word is an obstruction." The cultivation of a fairly broad vocabulary is desirable, but it is preferable to repeat the same word, if necessary to make the meaning clear, instead of adopting one that does not fit, for the sake of variety.

Lavoisier, writing on the expression of ideas in 1789, said:

> Every branch of physical science must consist of three things—the series of facts which are the objects of science, the ideas which represent these facts, and the words by which these ideas are expressed. Like three impressions of the same seal, the word ought to produce the idea, and the idea to be a picture of the fact. * * * As long as precise terms are lacking we can only communicate false or imperfect impressions of these ideas to others.

Having something to say, therefore, say it in your own way, provided you use good diction, the right word, and a simple form of expression. Above all, make your meaning clear. Read over each sentence to see if it expresses what you desire to say. Eliminate each word that is not necessary to the sense or the spirit of the article. Words are only useful for expressing ideas; fine writing and high-sounding phrases have no place in technical articles. Choose your words with care. Make each sentence convey an idea, and don't try to put more than one idea in a sentence. Punctuate so as to bring out your meaning; the punctuation is a part of the writing.

On this subject of lucidity in writing, I should like, even at the risk of some repetition, to quote from Dr. Erwin F. Smith, of the Department of Agriculture, who has given some remarkably good advice on writing.[2] He says:

> Clarity is the soul of truth, and especially in science there should be an idea behind every expression, and this idea should be stated as clearly as language permits. * * * There are various ways of saying things, but only one best way. Nevertheless, to read the contributions of many scientific men one would suppose they must think any method of expression sufficient, even the most clumsy and ambiguous. Yet such is not the case. In spite of this motley array of bad writers, it is best that subject and predicate should agree, * * * and especially that each statement should be susceptible of but one interpretation.
>
> Every paragraph and sentence in your paper should receive careful and repeated consideration, first, as to whether it tells the exact truth; second, as to whether it is absolutely clear, i. e., will convey the same meaning to all as to yourself; third, as to whether it is complete, or requires various additions or qualifications (science is an eternal qualification); fourth, as to whether the sentences in it are entirely logical and move convincingly toward your final conclusions. These things can be determined only by repeated readings and much pondering. * * * Occasionally there is a person who can write a thing as it should be the first time trying, but I have known only one or two such persons. Generally, easy writing is hard reading. Darwin sometimes recast his paragraphs a dozen times, and most of us may expect to reach a good style, if at all, only by dint of much labor and repeated rewriting. Yet who can doubt that it is an end worth all it may cost?

USE THE SIMPLEST WORDS THE SUBJECT WILL BEAR AND NOT TOO MANY OF THEM

So remember the reader. Be sympathetic toward him. He must make some effort, but he is not bound to follow you through. The writer has not the same hold on his audience that the speaker has. You may have to see it through if you get into a dull or unprofitable lecture, but the reader does not have to stay by an article that is hard to follow, badly put together, or tedious in its extravagant length. The author must interest and hold the reader if he expects to accomplish his purpose in publication. If a paper is direct and understandable, and has something worth while to say, it will be readable and interesting—often entertaining. If it is not interesting it will not be read, or only skimmed as a matter of duty. It is not always the fault of the public or of brother scientists if they are not familiar with your published work; a part of the burden rests on you.

Study to communicate the results of research in a way that will involve the least effort on the part of the reader to take them in. Spencer said that "Those are the most effective modes of expression which absorb the smallest amount of the recipient's attention in interpreting the symbols of thought, leaving the greatest amount for the thought itself." Technical articles naturally require rather close attention in reading, but it is poor writing when a sentence or a passage must be reread two or three times to get at its meaning. Writing that leaves the reader's mind in such a condition that it can uninterruptedy follow the meaning of the paper without being conscious of the words has been described as good style. Huxley's idea of style was "to say that which has to be said in such language that you can stand cross-examination on each word."

Brevity is another important quality of a technical paper. This does not mean that the presentation should not be adequate to a clear understanding of what is reported and ability of the reader to judge the merits of the contribution; but the length should be proportionate to the actual contribution. Nowhere are more skill and judgment required.

A publication is not judged by its length but by the message it carries. The amount of well-directed and well-digested work it represents, the discrimination shown in distinguishing between the important and the relatively unimportant, and conciseness in presenting the essential features are its claim to recognition.

Verbosity and diffuseness suggest a possible lack of really important matter to fill out the space, or at least that the writer has not digested what he has to say. As one writer puts it: "Verbosity is a sign either of carelessness or of a lack of time to take care."

The question of what to include will be determined to some extent by the character of the publication; but whether it is a technical or a semipopular one, the question of what to leave out will be one for very careful consideration, which frequently can not be settled at the first writing. On review it may be found that considerable may be left out without sacrificing anything really essential. Descriptions and statements of facts gain force by brevity and by sticking quite closely to the real kernel of the subject.

As a rule, the more definitely a fact has been established by an investigation, the more directly and simply it can be presented. It is the doubtful ones that have to be hedged about with explanations, qualifications, and cautions.

On this subject of brevity Doctor Smith says:

> A good rule is never to use two pages for a subject that can be compressed by a little thinking into one. The generality of men use more words to express an idea than are actually necessary, if the best words had been chosen. Study the meaning of words, their shades of meaning, and rewrite a subject twenty times, if necessary, to state it cogently and with brevity. Remember nearly everybody will read a brief statement on an interesting subject, while only the most phlegmatic

[2] Bacterial Diseases of Plants, by E. F. Smith, pp. 643-647.

and determined will hold themselves to a long-winded one. You will more than treble the number of your readers by halving your paper.

Morever, for the necessity of those who can't spend even the minimum of time necessary to read a short paper, and for the convenience of everybody, especially of the foreigner, it is your solemn duty to sum up the substance of your contribution in a series of brief conclusions which everyone will read, and which, if well put, may induce many to turn back and read your whole paper.

The style of the technical paper should be simple, straightforward, and dignified. It should suggest neither a fairy tale, a sensational newspaper story, nor a sermon, but rather a simple, unaffected, and uncolored account of work done and its application. Accuracy and clearness ought never to be sacrificed to a supposedly more popular style. The presentation should be such as to win the reader's confidence in the thoroughness and reliability of the work reported.

Accuracy of fact and statement is, of course, a primary requirement in technical writing. Carelessness is intolerable, a reflection on the author which can not be shifted to the stenographer or the printer, even though these may be found at fault. The investigator who is careless in reporting his work lays himself open to the suspicion that he may be careless in his experiments, in taking data, and even in thinking about them.

PLAN BEFORE YOU WRITE

With these things in mind, what should be the method of preparing for publication? I have no new receipt, no suggestion that has not been made by others, but with this acknowledgment I may attempt to put into form some of the essentials we have been discussing.

In presenting a scientific paper or a bulletin the author says, by inference at least: "Here is the product of my labors upon this subject, taking advantage of what others have done and building upon that foundation. I present it because the work has reached a stage which marks an advancement worth recording. I give it to you in a simple and straightforward form which will enable you to understand the status of the subject, my contribution to it, and its bearing or application. It is the product of my investigation and my mature judgment. I am ready to stand by my work and to be judged by this account of it."

Schopenhauer divided writers into three groups. The first and largest group wrote without thinking; the second thought and wrote at the same time; and the third group, a very small one, thought before they even began to write.

Outline or plan.—It is a good idea, therefore, to begin with the making of an outline or plan to be followed in constructing the article. Order is the first law of nature; hence an account of research dealing with a study of nature ought to reflect this quality in its arrangement. One of the first requirements is that the paper should be systematic, orderly, and logical in its method of presentation, progressive in its effect, so that the course can be followed and interest will cumulate to the very end.

The title.—First in order will come the title. This can not always best be determined at the beginning, but it has to be provided for, and so may be considered here. It is a matter of much more importance that it is sometimes thought to be. Of course there is a limit to what can be put into a title, but it should be specific and descriptive as far as it goes. Bibliographers complain bitterly of misleading or incomplete titles, and as bibliographies, abstracts, and indexes must be depended on for finding a paper after it is a few years old, an inadequate title is one means of burying a piece of research.

There have been several articles in Science recently on the proper wording of titles of scientific papers, especially from the standpoint of the librarian and bibliographer. In one of these an earnest plea was made for such clear and definite titles as will enable the accurate cataloguing of articles, so that the investigator must find them in his search for the literature.

The introduction.—Next will come the introduction, which, in an account of research, would set forth the problem and give a brief review of the recent literature bearing on the subject. Such a review should rarely constitute a monograph of all that can be found, as is sometimes the case, but be sufficient to show the status when the writer entered the field and the place where his work began. This will naturally make clear what the specific object of the research was—whether the adding of a new fact or idea, or a further interpretation.

This introductory matter will usually constitute a relatively small part of the article and be confined to what is strictly pertinent to the subject under discussion. It should not suggest what the old lady referred to as a *preramble.* Dr. E. E. Slosson, of Science Service, gives the following advice in this connection: "Don't back up too far to get a running start. Remember the man who wanted to jump over a hill. He ran a mile to work up momentum and was so tired when he got to the bottom of the hill that he had to sit down and rest. So will your readers be. Ninety per cent of the manuscript that I have handled in 20 years as an editor would have been improved by cutting off the first page or paragraph. Yet authors, like hens, kick on decapitation."

Body of the article.—We are now ready for the account of the investigation itself. Begin at the beginning, and let the account unfold itself in a systematic, logical way, as a verbal account of some experience would, but with the possibility of doing even better. When we are talking we often revise a somewhat confused statement by "that is to say" or "in other words," which indicates dissatisfaction with the way the matter has been put, and that in translating his thoughts into words the speaker has clarified his own thinking. This correction will usually be taken care of in the revision.

The reader will naturally be interested in a brief statement of the plan of procedure, the method employed, an indication of the scope of the study, and conditions under which it was done. The account will aim to show that the writer had a clear purpose in starting the work, realized what he was going after in his investigations, has the facts arranged in his own mind, and has studied them so that he can impart them to others and draw warranted deductions and conclusions.

REMEMBER THE READER

To quote Doctor Slosson again:

Don't overestimate the reader's knowledge, and don't underestimate the reader's intelligence He may not know as much as you do about this particular thing—let's hope not, anyway—but otherwise he may be as bright as you are—let's hope so, anyway.

Don't forget that your reader is interrupting you every 10 lines to ask "Why?" "What for?" or "Well, what of it?" and if you don't answer his tacit questions he will soon stop reading.

Don't shoot in the air. Aim at somebody. You may miss him, but you are more likely to hit somebody else than if you aim at nobody. Look out of your window and note the first person coming along the street. Imagine yourself stopping the man or woman on the sidewalk and, like the ancient mariner, holding his or her attention till you have told your tale to the end.

Analyze the subject carefully and break it up into parts. Use center heads and side heads in the text to divide it and express the relation of parts. This helps in the progressive arrangement and assists the reader to follow. Paragraph freely, separating different points in this way and bringing together things which belong together. This makes the page look less solid and makes reading easier.

As far as possible finish each topic or phase of the subject as you go along. Do not revert to it further on in the text to add some new point. This makes confusion. When comparisons are made between different parts of the paper, refresh the reader's mind sufficiently so that he will not necessarily have to turn back and reread in order to understand the new point.

Data and tabular matter.—A preliminary step toward writing is the preparation of the data. It is often possible to work up the data as the investigation progresses from one stage to another. This is helpful in connection with deciding on the next step. Before writing, the results will need to be critically reviewed to determine what they show and how they can best be arranged. The arrangement of data is an important part of the task of presenting the matter to someone else.

This occasion will be one for sifting, condensing, and summarizing. It is a selective process. I know there are those who contend for the publication of all the important data, so that readers may not only follow the author's reasoning but be able to check up critically on his deductions. Some writers insist on a practical reproduction of their notebooks, but this seems rarely warranted or necessary. Liberality should be exercised, of course, but the permissible liberality is determined in no small measure by the character of the article. The main object is to record matters which have permanent value, confessedly a matter of good judgment, in which there is perhaps as much danger of overestimating the importance of details as of leaving out too much.

The object of a table is to present a picture of the data, as complete in itself as possible. The purpose of tabulated data is not alone to record it, but to clarify the subject—to present the matter more clearly and concisely than it could be presented in the text. A table is a difficult thing for many people to make and for others to understand, particularly if it is unduly complicated or improperly constructed. The reader should be prepared for it by a text which leads up to it with a simple and direct explanation and a suitable title which tells what it is about. There is often room for improvement in such headings. Sometimes tables are designated merely by number. Do not cover too many different points in a single table. This makes the table complicated and leads to confusion, and it often results in including things which must be referred back to in the discussion several pages beyond. Long tables are apt to be confusing.

Try to avoid putting different units in the same column, as pounds, tons, dollars, etc. Sometimes this is necessary, but usually it can be avoided by turning the table about. As far as possible, tables ought to be self-explanatory, but sometimes the different treatments or variables are indicated by letters or numerals requiring reference to the text to supply the information, which usually is difficult. The table ought to clearly indicate the essential variables.

Don't forget that the reader will expect the author to make some explanation of what he considers a table shows, or how it prepares for what is to follow. It was not unusual in the past to "let the results speak for themselves," presenting them with no attempt at comments or comparison. Frequently this reflected a difficulty of interpretation, and so raised the question as to why such data should be inserted if the author himself was not able to make anything out of them.

THE SCYLLA OF OVERSTATEMENT AND THE CHARYBDIS OF UNNECESSARY QUALIFICATION

Avoid qualifying unnecessarily or too extensively. The aim should be to make fairly definite statements regarding the teachings of the investigation. These may be limited in their scope, but they ought to be direct, so that they can be understood. This is true whether they are conclusions, generalizations, or tentative suggestions. It is important to make the meaning clear, to be cautious and reserved, keeping well within the facts; but there is such a thing as being too cautious and too reserved, as if the author were not sure what he believed. It is a good rule to say what you have to say so people will give you credit for your suggestion or deduction; if not, it will be difficult to establish claim to originality later when some one else makes a positive announcement.

Illustrations.—A good illustration is often the quickest way to convey an idea. Frequently it will do the work of a whole page of description. The same is true of the presentation of results in graphic form, provided such graphs are not so complicated as to require an undue amount of study. The object of illustrations is to illuminate the text but not to embellish it—to make it more intelligible or to give a more definite impression. There is sometimes a tendency to overillustrate, which is a decided disadvantage in a scientific article. Aside from the expense this entails, it is confusing to the reader to be constantly running upon illustrations which are naturally supposed to have some bearing on the text, but after some waste of time are found not to have. Where possible there should be a reference to each figure or illustration in the text, and each figure should have a legend or title, telling what it illustrates and explaining it where necessary.

Conclusions.—The reader will expect some conclusions. He may be suspicious if there are too many or if they are too far-reaching. The author here has the opportunity of crystallizing the results and showing how they clarify the subject. The important points developed in the investigation should be brought together, with such deductions, suggestions, or generalizations as seem warranted. The accurate drawing and stating of these conclusions is one of the most delicate steps in preparing a scientific paper, requiring not only caution and discrimination but unusual care in wording to avoid possible misunderstanding.

After the paper has been entirely written, revise it clearly for the plan and method of presentation, and for the form of statement. This will frequently result in shortening the paper and making it more direct in its treatment, and it will give opportunity for the weighing of each statement for accuracy and clearness. If possible have some one else read it who has techincal knowledge of the subject. Prefer criticism before rather than after publication. It is usually more agreeable.

Most institutions or organizations now have provision for some editorial review of the manuscript before it is sent to the printer. The editor's task is a delicate one. It calls for tact, sympathy, and patience, but he is in a position to render a real service to writers of technical papers, and his efforts should be welcomed and given respectful consideration.

THE WAGON AND THE ELEVATING GRADER

AN ECONOMIC STUDY OF THE WAGON-ELEVATING GRADER COMBINATION, IN THREE PARTS

BY THE DIVISION OF CONTROL, U. S. BUREAU OF PUBLIC ROADS

Reported by J. L. HARRISON, Highway Engineer

PART III.—ESTIMATING THE COST OF ELEVATING-GRADER WORK

THE output of the elevating grader as used in highway construction and the importance of the attendant haul have been discussed in previous articles of this series. This article deals with the wagon supply and shows the application of the data secured to a few of the practical problems of the engineer and the contractor, particularly those encountered in preparing bids and controlling going projects.

As in the study of the other forms of earth-moving equipment, the determination of the number of wagons required is made on the basis of a time-distance graph, the pitch of which shows the rate at which the wagons are moved. In its general characteristics the typical time-distance graph for standard 1½ cubic-yard wagons is similar to those for the wheeler and fresno, but its pitch is higher than that of the fresno graph and not so high as that of the wheeler graph. Dynamometer studies are being conducted by the Bureau of Public Roads for the purpose, among others, of analyzing the reasons for this difference. While these studies have not yet advanced far enough to yield conclusive data, they appear to show that the power required to haul loaded wagons is less than that required to haul loaded fresnoes and greater than that required to haul loaded wheel scrapers. This presumption seems to be confirmed by the greater apparent variation in the rate at which wagons operate than in the rate at which either wheelers or fresnoes operate. In one or two instances, jobs have yielded a wagon time-distance graph indicating a rate of travel nearly as high as that commonly maintained by wheel scrapers. On the other hand, wagon jobs not infrequently show a rate of travel somewhat under that here presented as standard. This suggests that if the soil and gradient are favorable, the resulting light draft tends to bring the wagon speed up to the wheeler speed, while unfavorable soil conditions or adverse gradients increase the power required of the teams with a corresponding tendency to decrease the rate of travel.

Low rates of wagon travel appear also to be associated with a low rate of movement by the elevating grader. If the elevating grader is operated at less than its proper speed (3¾ feet per second) it is necessary to rein in the wagon teams while the load is being put on and they are apt to hold to the slower pace when moving with the load. The remedy is in efficient superintendence.

The pitch of the standard wagon graph, Figure 1, indicates a normal travel speed of approximately 245 feet a minute, or about 4 feet a second. The rate tends to be a little higher on the return empty than on the loaded haul. In estimating elevating grader work, however, the normal rate may be used unless the physical conditions prevailing on the job are such as to indicate that the hauling will be unusually difficult.

METHODS OF DETERMINING WAGON SUPPLY REQUIRED

For use in estimating the number of wagons required Tables 1 and 2 have been prepared. Table 1 shows the number of loads per hour which each wagon should move at the above normal speed for various lengths of haul. Table 2, among other things, shows the output of the grader, with average management for various lengths of cut. With these data, the number of wagons that should be supplied for any given length of wagon travel can be readily determined. For example, assuming normal operation in a 600-foot cut with an average haul distance of 700 feet, we find from Table 2 that the possible grader output in a 600-foot cut is 86 loads per hour and from Table 1 that a wagon normally operates at the rate of 8 trips per hour on a 700-foot haul. It follows, therefore, that eleven 1½ cubic-yard wagons will be required to supply the grader.

The same determination can be made graphically by use of the graph presented in Figure 2. Following the vertical line representing the 600-foot cut until it intersects the horizontal line for the 700-foot length of haul, we find that the intersection falls between the curves for 10 and 11 wagons, respectively. Whenever the determination yields a fraction of a wagon greater than one-half an additional wagon should be supplied, except that if the number of wagons indicated is five or less, an additional wagon should be supplied if the fraction is larger than a quarter. This is desirable because too much trotting of the

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ON ELEVATING-GRADER jobs variation in the length of cut and the wagon haul from the cut to the fill introduces an element of risk which is not present in grading jobs on which fresnoes or wheelers are to be used.

The fact that the earth is excavated by one unit and hauled by another makes the economical planning and performance of the work a somewhat complicated and difficult matter. Unless there is proper adjustment of the two units one to the other, so that the grader will excavate enough material to keep the wagon train busy, and, *per contra*, that a wagon will be in position for a load whenever the grader is ready to load it, there is a loss in production which, if frequently repeated, may consume the contractor's profit.

The quantity of earth the grader will excavate in a day depends upon a number of conditions which have been discussed in detail in a previous article; but one of the principal governing factors is the length of cut, since the time consumed in turning the grader is necessarily unproductive. The number of wagons required to keep the grader busy depends upon the length of haul.

On all jobs there is some variation in the lengths of cuts and hauls, and it is not practicable, therefore, to plan the work so as to obtain maximum efficiency of the wagons and grader at all times. But for any job there is some best size of wagon train which will reduce the cost of the work to a practicable minimum.

This article describes a method by which, for any particular job, the economic size of wagon train can be determined; and the probable cost can be estimated with a minimum of risk.

TABLE 1.—*Number of loads per wagon per hour for various haul distances*

Haul distance	Time per round trip	Number of trips per hour	Haul distance	Time per round trip	Number of trips per hour
Feet	*Minutes*		*Feet*	*Minutes*	
100	2.57	23.3	900	9.12	6.6
200	3.39	17.7	1,000	9.94	6.0
300	4.21	14.2	1,200	11.58	5.2
400	5.03	11.9	1,400	13.22	4.5
500	5.85	10.2	1,600	14.85	4.0
600	6.66	9.0	1,800	16.49	3.6
700	7.48	8.0	2,000	18.13	3.3
800	8.30	7.2			

TABLE 2.—*The effect of length of cut on percentage of time grader is nominally at work. Average operation with adequate supply of 1½ cubic-yard wagons*

[Loading distance, 75 feet; loading time, 23 seconds; exchange time, 11 seconds; grader turning time, 45 seconds; grader delays, 10 per cent]

Number of loads	Length of cut	Wagon-loading time	Average wagon exchange	Grader-turning time	Time losses due to breakdowns, rests, etc. (10 per cent)	Total time	Loads per hour	Percentage of time grader is at work	Percentage of production on basis of 450-foot cut and adequate wagon supply
	Feet	*Seconds*	*Seconds*	*Seconds*	*Seconds*	*Seconds*	*Number*	*Per ct.*	*Per ct.*
1	75	23	--------	45	7	75	48	30.6	58.0
2	150	46	11	45	10	112	64	41.1	78.0
3	225	69	22	45	14	150	72	46.0	87.2
4	300	92	33	45	17	187	77	49.2	93.4
5	375	115	44	45	20	224	80	51.4	97.4
6	450	138	55	45	24	262	82	52.7	100.0
7	525	161	66	45	27	299	84	53.8	102.0
8	600	184	77	45	31	337	86	54.6	103.6
9	675	207	88	45	34	374	87	55.3	105.0
10	750	230	99	45	37	411	88	56.0	106.2
15	1,125	345	154	45	54	598	90	57.7	109.3
20	1,500	460	209	45	71	785	92	58.6	111.1

N. B.—A loading loop consists of a run down the cut, a turn, a run up the cut and a second turn. In developing this table a half loop—one run and one turn—has been used. By this device the "length of cut" may be compared directly with plans for construction work. Output, working time, etc., are the same as they would be if a whole loop had been used.

stock would be necessary if only five wagons are required to make up an average deficiency as great as a full half wagon, which is 10 per cent of the total wagon supply. While a well-managed wagon string can safely carry a 10 per cent overload for a considerable period, it is easier to operate smoothly on a 10 per cent underload, and unless the superintendence is of a high order the loss in output which is likely to result from the attempt to carry an overload will more than counterbalance the saving in cost of team time.

Figure 3 shows the wagon supply required under average management if 2 cubic-yard wagons are used instead of the 1½ cubic-yard wagons assumed in Figure 2. These graphs are based on the rate of wagon travel shown in Figure 1 and on the conditions noted on the graphs.

Often an outfit will be operated somewhat above average efficiency in one or more of the details most important in govering production. For such outfits the wagon supply should be somewhat larger than is indicated in Figures 2 and 3. To cover such cases the graphs shown in Figures 4 and 5 have been prepared, and from them may be secured the information for use in estimating the wagon supply required when increased efficiency is secured from whatever cause. Line A gives data for average management. Line X gives data for a 5-second saving in total time per load; lines Y and Z, for savings of 10 seconds and 15 seconds, respectively, while line B is for extra-good management, where about 16 seconds are saved. Figure 4 is for use with the graphs in Figure 2 when wagons of 1½ cubic yards capacity are used, and Figure 5 with Figure 3 when wagons of 2 cubic yards capacity are used. The conditions under average management as contrasted with extra-good management, shown as line B in Figures 4 and 5, are given in the following table:

Item	Unit	1½-cubic-yard wagons		2-cubic-yard wagons	
		Average management	Extra good management	Average management	Extra good management
Loading distance	Feet	75	60	107	90
Loading time	Seconds	23	16	35	24
Exchange time	do	11	5	11	5
Grader turning time	do	45	45	45	45
Grader delays	Per cent	10	5	10	5
Grader speed	Feet per second	3.26	3.75	3.26	3.75
Wagon speed	do	4.08	4.08	4.08	4.08

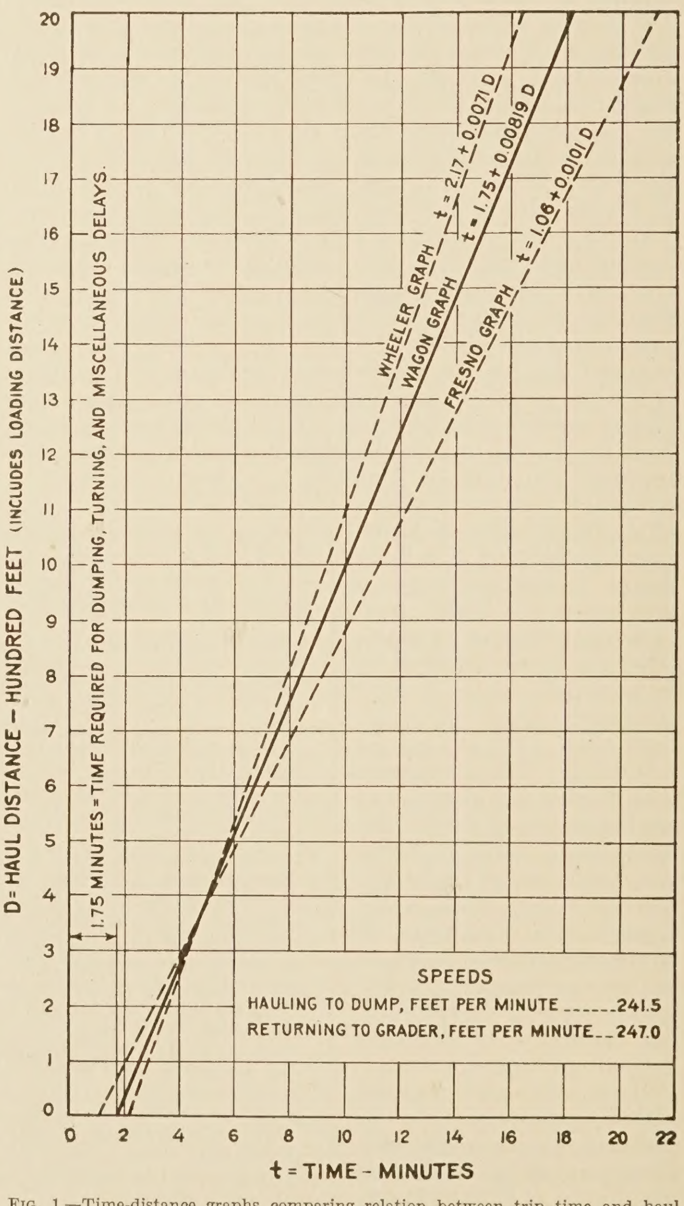


FIG. 1.—Time-distance graphs comparing relation between trip time and haul distance for wagons with similar relation for fresnoes and wheelers

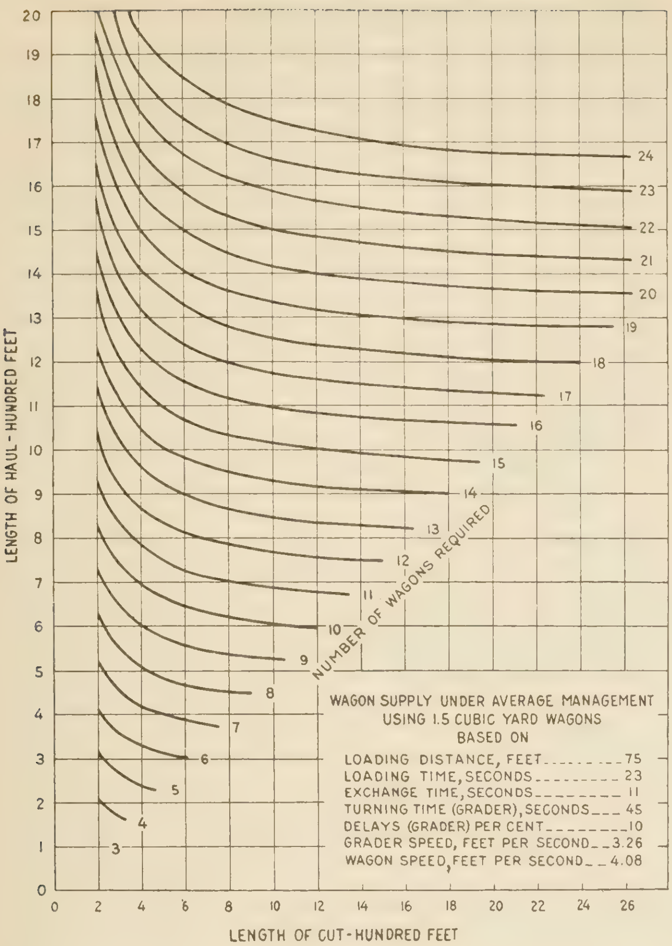


Fig. 2.—Curves for use in determining the supply of 1½ cubic-yard wagons required for various lengths of haul and lengths of cut with average management

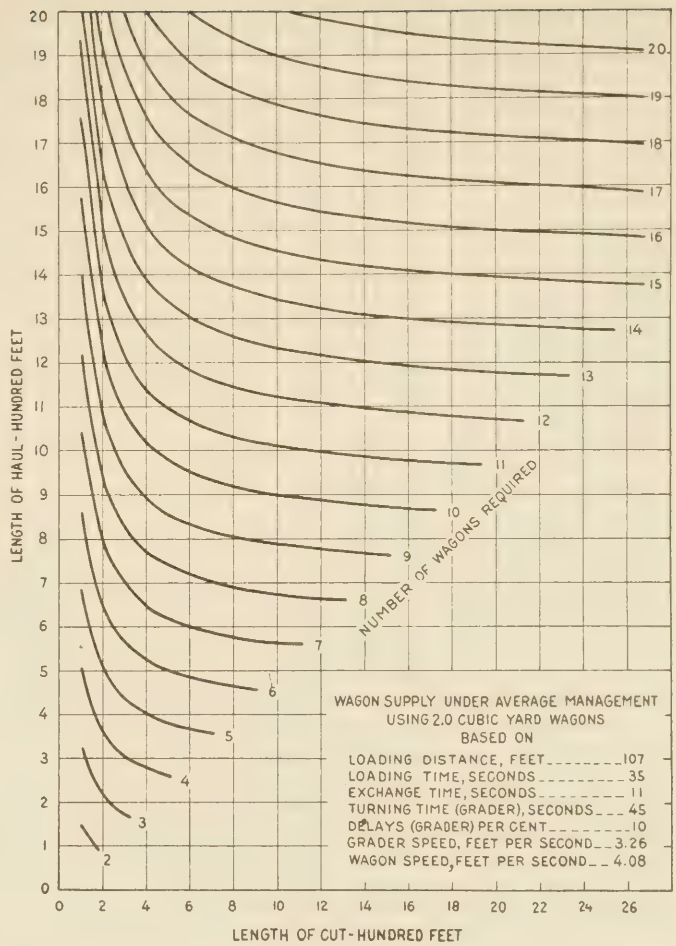


Fig. 3.—Curves for use in determining the supply of 2 cubic-yard wagons required for various lengths of haul and lengths of cut with average management

To demonstrate the use of the graphs, let us suppose the wagons used are of 1½ cubic yards capacity. We find from Figure 2 that under average management, with a length of cut of 600 feet and haul of 700 feet, the required wagon supply is 10.8 as previously stated. To determine the wagon supply needed under extra good management, we refer to Figure 4 and follow the vertical line for the 600-foot cut to its intersection with line B; then, following horizontally to the percentage scale at the left, we find that the wagon supply should be 160.5 per cent of the supply required for average management or (10.8×1.605) 17 wagons. For cuts of average length (approximately 450 feet long) the first five seconds saved (line X) increases the wagon supply required about 13 per cent, or at the rate of about 2.6 per cent for each second saved. As the increased wagon supply is required by increased production, the importance of each second saved is very apparent. The second five seconds saved (line Y) requires a further increase in wagon supply of about 17 per cent, or at the rate of 3.4 per cent per second. The third 5 seconds saved (line Z) requires an increased wagon supply at the rate of about 4.6 per cent per second. Where management is below the average the effect is, of course, reversed.

To use these graphs it is necessary to know what average loading time is being secured, the length of cut, the percentage of time the grader is idle, and the exchange time. If these conditions are as shown in Figure 2 or 3, which we call normal, the wagon supply is read directly from the graphs using Figure 2 or Figure 3, depending on whether 1½ or 2 cubic yard wagons are employed. If the observed conditions indicate that higher efficiency is being obtained determine the amount by which the normal loading time is reduced and, after ascertaining from Figure 2 or 3 the number of wagons required for average management, correct the result by increasing the number as indicated by the percentage read from Figure 3 or 4 opposite the intersection of the vertical line through the appropriate cut length figure with the horizontal line representing the time saved. Thus, by reference to Figure 2, we find that when working from a 450-foot cut on a 600-foot haul the wagon supply required under normal or average conditions is 9.2. But if a saving of 6 seconds is being made reference to Figure 4 shows that the wagon supply should be 116.4 per cent of the normal, or 11.

TIME LOSSES IN WAGON OPERATION

The constant losses involved in wagon operation are, in their general nature, similar to those encountered in the operation of other forms of earth-moving equipment. They include turning time, dumping, and miscellaneous waits. The field observations indicate that not much time is lost on the turns or in the dumping operation, which is simple and rapid. The principal avoidable losses are caused by: (1) Improper dump-

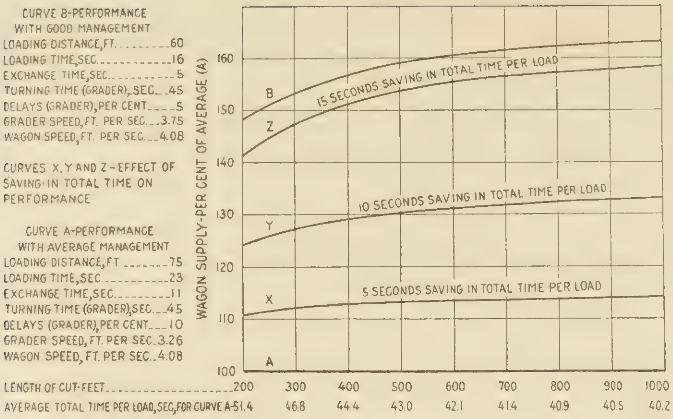


FIG. 4.—Increase in supply of 1½ cubic-yard wagons required by increased efficiency in operation of grader and wagons

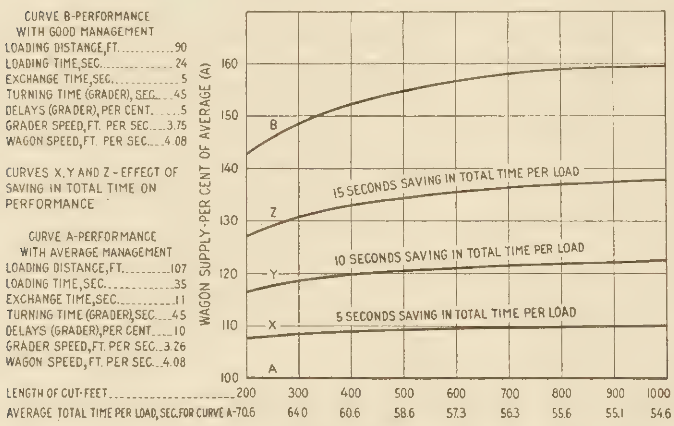


FIG. 5.—Increase in supply of 2 cubic-yard wagons required by increased efficiency in operation of grader and wagons

ing practices; (2) the practice, found on most jobs, of allowing teams to maintain a fixed position in the string; and (3) the use of an unnecessarily large number of wagons on the work. Loading (by the method of analysis used in this article) is included in the wagon travel time. A little time may be lost in loading by the checking of the normal wagon speed to conform to a lower grader speed, but this loss can be avoided only by a correction of the grader speed.

Handling material at the dump is an art. The dump man must have two separate objectives in mind—(1) the building of a neat and workmanlike fill and (2) the disposition of material as delivered without delaying the wagons. The first of these objectives is most easily accomplished by end dumping, for the reason that the dump man can preserve line and grade simply by setting a few shoulder stakes. But the practice of end dumping, aside from the fact that it produces a fill which will settle considerably more than a layer-dumped fill, is undesirable from the contractor's standpoint, because the dumping area is necessarily so small that the Mormon scraper or light blade used in distributing material and forcing it over the end of the dump can not work without more or less interruption by the wagons. Layer dumping enables the dump man to provide all the dumping area needed in handling material, no matter what the rate of delivery may be. On the other hand, it is a little more difficult to place a fill accurately if layer dumping is practiced and the number of dump men who can build a trim and regular layer fill is limited. That it can be done, however, with no additional cost to the contractor was demonstrated on a job studied at Jordan, Minn., during a considerable part of the past working season. The fills on this job, ranging from 1 or 2 feet to over 20 feet in depth, were placed by a skilled dump man and a two-horse blade with driver so accurately that even after allowing a reasonable period for settlement the engineers found that in many cases final dressing was not really required before the work could be accepted. This case is mentioned because it indicates the accuracy with which layer dumping can be performed if a really skilled dump man is in charge of the work.

On elevating-grader jobs it is customary to permit the drivers to maintain a regular position in the wagon string. Working under this system, it is not uncommon to see practically the whole string held up because one driver has stopped his team for some reason. It is even more common to see one or two wagons held up at the dump because one driver has been somewhat detained in dumping. In the course of a day's work, this practice may result in considerable delay. If the time losses at the dump are to be reduced as far as possible, it can best be accomplished by requiring teamsters to accept whatever position in the line falls to them. This would also measurably avoid one of the objections that some contractors have to layer dumping, namely, that it tends to disorganize the wagon string.

The last and perhaps the most important cause of miscellaneous delays is traceable to having too many wagons on the work. As now commonly operated the elevating-grader outfit consists of grader and a fixed number of wagons. These the contractor customarily sends out every morning without much regard to whether they can be used effectively or not. As a result, if the haul is short, there is a considerable surplus in the wagon supply which appears in long waits between loads, and sharply increases the lost wagon time. This has been discussed in another part of this article[1] and a method of avoiding the trouble suggested.

ESTIMATING THE COST OF ELEVATING-GRADER WORK

Turning now to the method of estimating, it may be stated at the outset that the process is somewhat complicated. In the first place, the contractor should know his general efficiency and whether or not he will expect as a matter of policy to supply an adequate wagon train. It has been made clear that where no particular attention is paid to the adequacy of the wagon train, the exchange of wagons at the grader is likely to reach 20 seconds or more as an average. If an adequate wagon supply is maintained, the exchange, under normal efficiency, drops to about 11 seconds; and, if the superintendence is of a high order, it can be driven down to about 5 seconds. Other phases of this matter might also be noted here, but will hardly be necessary in order to support the statement that any scheme of estimating, if successfully used, must reflect conditions of this sort. The procedure which is outlined below sets up a basis on which this can be done. As a method it may be followed with confidence, but it can not be followed blindly.

[1] See Public Roads, April, 1925, p. 30.

Briefly stated, this method of estimating is based on the assumption that the output will run a little over 100 cubic yards an hour on a job where conditions are normal or average, i. e., an average length of cut in which to work the grader, average efficiency in operation, a normal bite, an adequate wagon supply, and normal time losses, factors which have been found to generate a 23-second average loading time, an 11-second period for the exchange of wagons, a 45-second grader turn, and (with a 16-horse grader) a time loss of about 10 per cent, due to breakdowns, clean outs, miscellaneous rests, etc. As managerial policies generally reduce the working day to something under 10 hours, the actual output, these conditions prevailing, should be about 1,000 cubic yards per working day. As estimating must be done from some general basis this one has been selected. The development of the estimate then becomes a matter of determining the probable working time on the basis of governing factors. It should be observed that the 1,000-cubic-yard basis is dependent on the assumption of average efficiency under average conditions. It is here that the contractor should inject known data as to his own efficiency. He may, for instance, regularly take a bite that is a little larger than average, or he may obtain a rate of wagon exchange a little better than average. These or other conditions may increase his output under standard conditions; or he may find that with his outfit he can not reach this rate. The point to be emphasized is that he should keep accurate records and in this way ascertain whether, with his particular outfit, he can reasonably use 1,000 cubic yards as a standard output or whether he should use 900 or perhaps 1,100 cubic yards.

In making up the estimate, the first factor to be considered is the length of cut. It has been shown in another part of this article[2] that the length of cut has a marked effect on the output which can be secured from the grader, Figure 6 shows the effect of length of cut when efficiency is normal for both 1½ and 2 cubic yard wagon outfits.

In determining the length of cut the mean length should be used. Thus, if a 3-foot cut is to be taken out in four levels which, by a study of the plans, are found to be 200, 340, and 420 feet long, the length of cut should be taken as the average or, say, 300 feet. This will be a little high if cuts are short, as the production falls off with disproportionate rapidity under 300 feet. However, the number of cuts requiring very short runs is generally so small that the error from this cause will not be great.

The first operation in preparing the estimate is, then, to determine the effect of the prevailing length of cut on the output, the yardage produced from a 450-foot cut being assumed to be 100 per cent. In the case of a 300-foot cut, the output of a 16-horse outfit, with normal efficiency, will be 93.4 per cent. (See fig. 6, graph A.) If the cut contains 5,400 cubic yards the equivalent yardage is, then, 5,400 cubic yards divided by 93.4 per cent or 5,800 yards; i. e., it will take as long to produce 5,400 cubic yards from a 300-foot cut as it would take to remove 5,800 cubic yards from a cut of average (450 feet) length. The equivalent yardage should be determined by 1,000 cubic-yard units and residual fractions as subsequent calculations are best handled in this way. The result of this determination for a specific job is shown in Table 3, the cut data being obtained from the profile

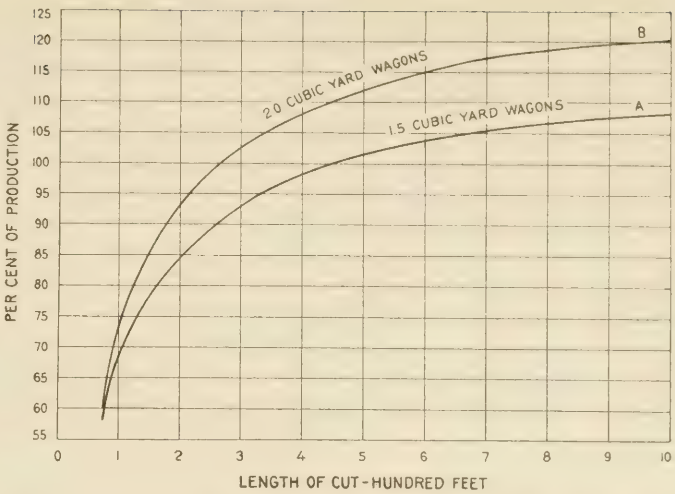


FIG. 6.—The effect of length of cut and size of wagons on production, operation with average management in a 450-foot cut with 1½ cubic-yard wagons being considered as 100 per cent. (See Table 2.)

shown in Figure 7 and the percentage of output from graph A in Figure 6.

The equivalent yardage would be a direct indication of the time required to handle the work if there were no long hauls. But there will generally be cuts from which the haul will be greater than can be handled by the wagon train that has been sent out with the grader. This will require a further adjustment of the equivalent yardage to allow for wagon shortage. In making this second adjustment the wagon travel is analyzed by the same 1,000-cubic-yard units to determine the wagon supply needed to handle each part of each cut; and, the needed supply being compared with the actual supply, another equivalent yardage is computed. The necessary wagon supply is read directly from the graphs shown in Figures 2 and 4 (or 3 and 5, depending on whether 1½ or 2 cubic-yard wagons are used); and the data on length of wagon travel and length of cut are secured from the mass diagram and the profile, repectively. The equivalent yardage due to length of cut and the equivalent yardage due to wagon supply are then scrutinized, and the controlling yardage is determined in each case by using the larger. The sum of the equivalent yardages so obtained divided by the average daily output (here assumed to be 1,000 cubic yards) is the number of days' work to be performed.

THE METHOD OF ESTIMATING ILLUSTRATED

For purposes of illustration fill 8 in Table 3 will be used. This fill contains 4,754 cubic yards, which must be obtained from a cut in which the average grader loop will be about 300 feet long. The average wagon travel, after adding 50 feet for wagon manipulation, is found from the mass diagram to be 1,175 feet for the first 1,000 cubic yards, 1,055 feet for the second 1,000 cubic yards, 940 feet for the third 1,000 cubic yards, 770 feet for the fourth, and 435 feet for the remaining 754 cubic yards of material. The percentage of production is found from Figure 6 to be 93.4 for a 300-foot cut. These data are tabulated in columns 2, 3, 4, and 5. Column 6, the result of dividing column 4 by column 5, gives the equivalent yardage due to length of cut and would be an indication of the time required to move the yardage into fill 8 if the wagon supply were adequate at all times. This wagon supply, as previously explained, is obtained from Figures 2 and 4 or 3 and 5, depending on whether 1½ or 2 cubic-

[2] See Public Roads, May, 1925.

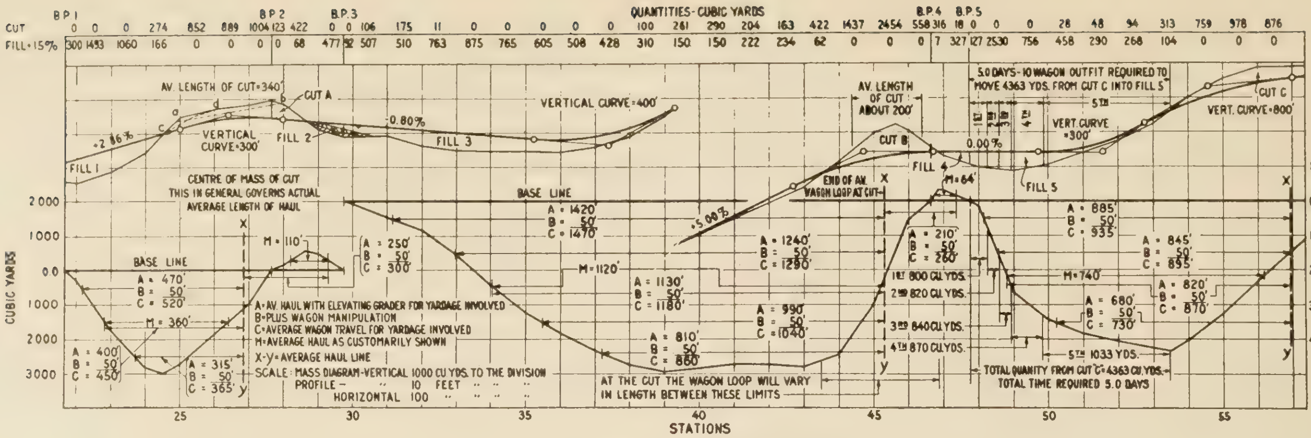


FIG. 7.—Design of sample grading project

TABLE 3.—*Method of finding economical wagon supply. Cut data taken from design shown in Figure 7*

Fill No.	Length of cut	Haul, distance	Actual yardage	Percentage of production based on a 450-foot cut	Equivalent yardage due to length of cut	Wagon supply required	10-wagon outfit: Percentage of supply	10-wagon outfit: Equivalent yardage due to wagon supply	10-wagon outfit: Controlling equivalent yardage	11-wagon outfit: Percentage of supply	11-wagon outfit: Equivalent yardage due to wagon supply	11-wagon outfit: Controlling equivalent yardage	12-wagon outfit: Percentage of supply	12-wagon outfit: Equivalent yardage due to wagon supply	12-wagon outfit: Controlling equivalent yardage
1	2	3	4	5	6	7	8	9	10	8	9	10	8	9	10
	Feet	*Feet*	*Cubic yards*	*Per cent*	*Cubic yards*	*Number*	*Per cent*	*Cubic yards*	*Cubic yards*	*Per cent*	*Cubic yards*	*Cubic yards*	*Per cent*	*Cubic yards*	*Cubic yards*
1	340	520	1,000	95.5	1,048	8	100	1,000	1,048	100	1,000	1,048	100	1,000	1,048
		450	1,000	95.5	1,048	7	100	1,000	1,048	100	1,000	1,048	100	1,000	1,048
		365	1,019	95.5	1,067	6	100	1,019	1,067	100	1,019	1,067	100	1,019	1,067
2	340	300	545	95.5	571	6	100	545	571	100	545	571	100	545	571
3	200	1,470	1,000	84.1	1,190	16	63	1,585	1,585	69	1,450	1,450	75	1,335	1,335
		1,290	1,000	84.1	1,190	15	67	1,495	1,495	73	1,370	1,370	80	1,250	1,250
		1,180	1,000	84.1	1,190	13	77	1,300	1,300	85	1,175	1,190	93	1,075	1,190
		1,040	1,000	84.1	1,190	12	83	1,205	1,205	92	1,090	1,190	100	1,000	1,190
		860	725	84.1	863	10	100	725	863	100	725	863	100	725	863
		350	300	84.1	357	5	100	300	357	100	300	357	100	300	357
4	200	260	315	84.1	375	4	100	315	375	100	315	375	100	315	375
5	550	935	1,000	102.5	976	13	77	1,300	1,300	85	1,175	1,175	93	1,075	1,075
		895	1,000	102.5	976	13	77	1,300	1,300	85	1,175	1,175	93	1,075	1,075
		870	1,000	102.5	976	13	77	1,300	1,300	85	1,175	1,175	93	1,075	1,075
		730	1,000	102.5	976	11	91	1,100	1,100	100	1,000	976	100	1,000	976
		500	340	102.5	332	8	100	340	332	100	340	332	100	340	332
6	550	700	250	102.5	244	11	91	275	275	100	250	244	100	250	244
6a	550	1,765	1,000	102.5	976	23	43	2,330	2,330	48	2,085	2,085	52	1,925	1,925
		1,720	180	102.5	176	22	45	400	400	50	360	360	55	327	327
	300	665	820	93.4	878	9	100	820	878	100	820	878	100	820	878
		600	1,000	93.4	1,070	8	100	1,000	1,070	100	1,000	1,070	100	1,000	1,070
		510	1,000	93.4	1,070	8	100	1,000	1,070	100	1,000	1,070	100	1,000	1,070
		415	1,000	93.4	1,070	7	100	1,000	1,070	100	1,000	1,070	100	1,000	1,070
		325	340	93.4	364	6	100	340	364	100	340	364	100	340	364
7	300	465	1,000	93.4	1,070	7	100	1,000	1,070	100	1,000	1,070	100	1,000	1,070
		335	252	93.4	270	6	100	252	270	100	252	270	100	252	270
8	300	1,175	1,000	93.4	1,070	15	67	1,495	1,495	73	1,370	1,370	80	1,250	1,250
		1,055	1,000	93.4	1,070	13	77	1,300	1,300	85	1,175	1,175	93	1,075	1,075
		940	1,000	93.4	1,070	12	83	1,205	1,205	92	1,090	1,090	100	1,000	1,070
		770	1,000	93.4	1,070	10	100	1,000	1,070	100	1,000	1,070	100	1,000	1,070
		435	754	93.4	808	7	100	754	808	100	754	808	100	754	808
Casting			2,256	100.0	2,256				2,256			2,256			2,256
Total yardage			27,096						33,177			31,612			30,644

Cost per cubic yard for 10 wagons (outfit cost \$130 per day) 15.9 cents, for 11 wagons (outfit cost \$135 per day) 15.7 cents, for 12 wagons (outfit cost \$140 per day) 15.8 cents.

yard wagons are used; and in this illustration is found to range from 7 to 15 wagons (Figure 2 because average management has been assumed).

From the previous discussion and from column 7 of Table 3 it can readily be seen that an adequate wagon supply at all times would not only be uneconomical but practically impossible. Therefore, an economic wagon supply must be determined and for the first trial a 10-wagon outfit will be assumed. The first step then is to find the percentage relation of this trial outfit to the full wagon supply theoretically required to move each 1,000-cubic-yard unit

$$\text{column } 8 = \frac{\text{size of trial outfit}}{\text{column } 7}.$$

For a 10-wagon outfit, this relation for each of the units moved to fill 8 is $\frac{10}{15}$, $\frac{10}{13}$, $\frac{10}{12}$, $\frac{10}{10}$, and $\frac{10}{7}$, or 67, 77, 83, 100, and 100 per cent, respectively. It will be noted that where the number of wagons tested exceeds the number of wagons required, the percentage of wagon supply is still 100 per cent. This is due to the fact that the elevating grader has a definite capacity and, when the wagon supply exceeds the required supply production does not increase; the wagons simply lose time waiting for their loads. Now, by dividing the actual yardage by the percentage of wagon supply (column 4 divided by column 8) we obtain the equivalent yardage due to wagon supply (column 9). We

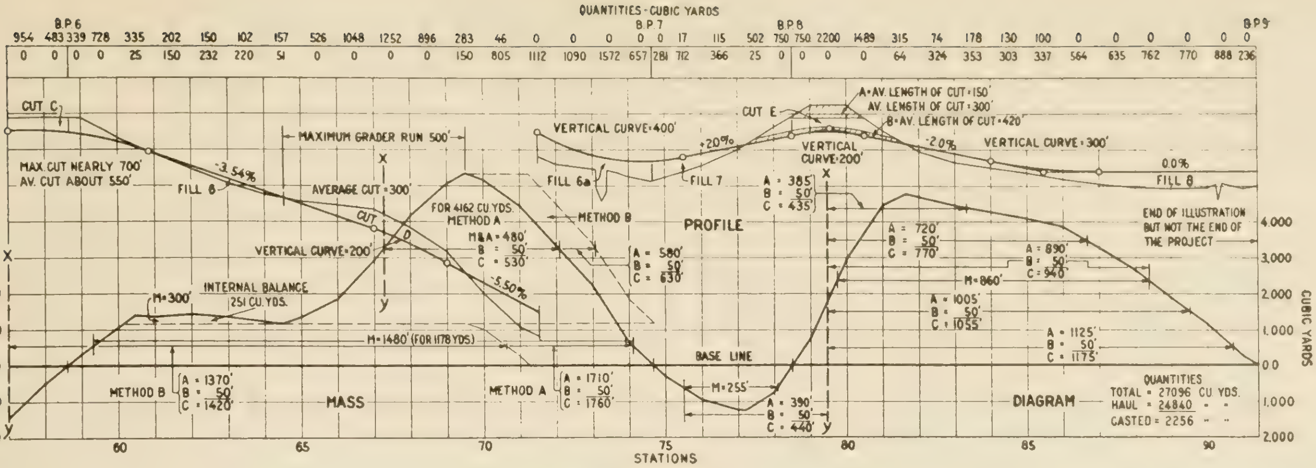


FIG. 7—Continued

compare this yardage with the equivalent yardage due to length of cut (column 6) and in each case place the larger yardage, which is the controlling equivalent yardage, in column 10. Material cast directly from the grader to the subgrade should also be tabulated in column 10. The sum of the controlling equivalent yardages (column 10) divided by the average daily output (assumed as 1,000 cubic yards) gives the number of days required to place the actual yardage shown in column 4. Similarly the time required for the movement of the same material with 11 and 12 wagon outfits may be determined; and it will be found that 33.2 days will be required for a 10-wagon outfit, 31.6 days for an 11-wagon outfit, and 30.6 days for a 12-wagon outfit.

The field costs will amount to about \$130, \$135, and \$140 per day, respectively (based on \$80 per day for the grader unit and \$5 per day for each wagon).[3] Therefore, the unit cost of production on this job with

Grader:	
17 horses (16 regular, 1 extra)	\$12.00
1 eight-horse driver (high seat)	6.00
2 four-horse drivers	9.00
1 plow shaker	10.00
1 wheel-stock man	4.50
	41.50
Dump:	
1 two-horse team	1.50
1 driver	3.50
1 dump man	8.50
	13.50
Miscellaneous:	
1 blacksmith	7.50
1 foreman	11.50
1 laborer (miscellaneous work)	3.00
Miscellaneous light repairs	3.00
	25.00
Wagons:	
10 wagons at \$5.00	50.00
11 wagons at \$5.00	55.00
12 wagons at \$5.00	60.00
Total field costs:	
10-wagon outfit	130.00
11-wagon outfit	135.00
12-wagon outfit	140.00

The above figures are illustrative only. In a general way they reflect field costs as they are to-day, but there is so much difference in wage standards in different camps, particularly in the higher positions, as well as in the composition of the working force—that no estimate of this sort can be set up as standard. Each contractor must make his own estimate based on his own wage scale and organization.

a 10-wagon outfit will be $\frac{33.2 \times 130}{27,096} = 15.9$ cents per cubic yard; for an 11-wagon outfit, $\frac{31.6 \times 135}{27,096} = 15.7$ cents per cubic yard; and for a 12-wagon outfit, $\frac{30.6 \times 140}{27,096} = 15.8$ cents per cubic yard, indicating that the economical supply is 11 wagons.

There are some minor adjustments which could be made in this sytsem of estimating to slightly increase its accuracy. The method used, however, has been found to yield results generally differing from those of the more detailed methods by less than a tenth of a cent per cubic yard. These minor adjustments, therefore, are felt to be of no practical value.

THE EFFECT OF DESIGN ON COST OF GRADING

There is a great variation in the relation between equivalent yardage and the actual yardage from project to project. This difference brings into view the effect of the elements of risk which have been discussed in this series of articles and offers at once a convenient and a valuable basis from which to study both design and the cost of construction. Obviously, the ideal project would be one so designed that the grader could always produce at least a standard output and that a normal wagon train could at all times handle all of this output. In that case actual yardage would equal equivalent yardage. But projects so designed are rare. Table 4 shows the actual yardage, the equivalent yardage, and the relation between them, for various wagon trains which might be selected for use on the three designs, A, B, and C, discussed in the second part of this article.[4]

In the original design, A, with the most economical length of wagon train, equivalent yardage exceeds actual yardage by about 17 per cent. This means, of course, that production will cost 17 per cent more on this project than it would cost on a project of ideal design requiring the same wagon train. In the first redesign, with the most economical length of wagon train, equivalent yardage exceeds actual yardage by about 13 per cent, and in the second redesign the excess is about 11 per cent. This indicates that in each of these designs there has been a failure to completely adjust the design to the most economical length of wagon train. From the contractor's standpoint it means that average production will unavoidably be below standard.

Such an analysis as the one here developed also makes it possible to select the most economical wagon train.

[3] Approximate field costs:

[4] See PUBLIC ROADS, vol. 6, No. 3, May, 1925.

TABLE 4.—*Actual and equivalent yardage and their relationship for designs A, B, and C*

Design	6-wagon outfit			7-wagon outfit			8-wagon outfit			9-wagon outfit			10-wagon outfit			11-wagon outfit			12-wagon outfit		
	Actual yardage	Equivalent yardage	Increase	Actual yardage	Equivalent yardage	Increase	Actual yardage	Equivalent yardage	Increase	Actual yardage	Equivalent yardage	Increase	Actual yardage	Equivalent yardage	Increase	Actual yardage	Equivalent yardage	Increase	Actual yardage	Equivalent yardage	Increase
	Cubic yards	*Cubic yards*	*Per cent*	*Cubic yards*	*Cubic yards*	*Per cent*	*Cubic yards*	*Cubic yards*	*Per cent*	*Cubic yards*	*Cubic yards*	*Per cent*	*Cubic yards*	*Cubic yards*	*Per cent*	*Cubic yards*	*Cubic yards*	*Per cent*	*Cubic yards*	*Cubic yards*	*Per cent*
Original, A													27, 096	33, 177	22	27, 096	[1] 31,612	17	27, 096	30, 644	13
First redesign- B							26, 573	31, 480	19	26, 573	[1] 29,887	13	26, 573	28, 947	9						
Second redesign, C	27, 446	33, 663	23	27, 446	[1] 30,445	11	27, 446	29, 419	7												

[1] Economical wagon train.

It will be observed that the number of wagons assigned to an outfit may materially influence the unit cost. This is, of course, due to the fact that as the size of the outfit increases the percentage of the total material which can be hauled without delaying the grader increases. However, the cost of operating the outfit increases as the wagon train increases. The two, therefore, tend to offset each other, a circumstance which accounts for the fact that for each job there is an outfit most economical for the haul conditions prevailing. So important is this latter phase that it should always be examined quite as carefully as the effective yardage. Thus, in the designs which have been used as an illustration, the most economical wagon train for design A is 11 wagons; for design B, 9 wagons; and for design C, 7 wagons. Increases or decreases from these wagon supplies would tend to cause increased production cost. This also has a bearing on cost, for obviously an outfit operating 11 wagons will cost more than one operating 7 wagons. In this case the net result is that under the original design even when 11 wagons are used the work will take 17 per cent more time than an ideal design would require, while in case C, with 7 wagons working, about 11 per cent excess time is required. The effect on production cost is obvious.

With an estimate developed in this way the contractor may schedule his work as described in the previous articles on wheelers and fresnoes.[5] It is not necessary to redescribe the method here. It may, however, be remarked that a time schedule of operation is quite as valuable a control on this work as on other grading work.

THE EFFECT OF THE CHARACTER OF THF EARTH MOVED

Nothing has been said in this article in regard to differences in the character of the material to be handled as affecting cost. The reason for this is that, as with other forms of dirt-moving equipment, the character of the material, while often differing a good deal from cut to cut, tends to average into rather a constant factor. Undoubtedly there is a difference in the power required in taking out different classes of material. In some the bull wheel functions better than in others. The dynamometer studies, now in progress, are expected to yield data on these points.

[5] See PUBLIC ROADS, vol. 5, No. 7, September, 1924; vol. 5, No. 8, October, 1924; and vol. 5, No. 10, December, 1924.

In rare instances, as where fine dry sand, especially heavy soil, and ground tending to become marshy, etc., will be encountered in considerable amount, the contractor should make allowance for soil conditions by reducing the assumed output from 10 to 30 or perhaps 40 per cent, as his experience may dictate. This will not, however, correspondingly increase production cost as his wagon train can be somewhat reduced if the output is likely to be consistently low.

Where bowlders will be encountered, the cost of the outfit per day should be modified to include under miscellaneous expenses the men and teams needed to get the rocks out of the working area. On the projects which have been studied the bowlders have varied from none to enough to keep two teams, with drivers and two extra men, at work all the time. As bowlders, even in some quantity, do not materially affect the output of the grader, the expense of removing them should be estimated as a miscellaneous expense, but generally there need be no allowance for reduction in output.

There are a number of other aspects of elevating-grader work which deserve consideration. Some of these require further study and others can be more appropriately considered in a general discussion of grading work. They are therefore omitted at this time.

WENDOVER CUT-OFF COMPLETED

The official opening of the Wendover Cut-off across the mud flats and salt beds of the Great Salt Lake Desert was held on June 13 at Salduro, Utah. The completion of the road, 41 miles long, opens the way for transcontinental and interstate travel between Salt Lake City and northern and central California and brings to a successful conclusion a five-year effort to bridge the age-old obstacle of the salt desert.

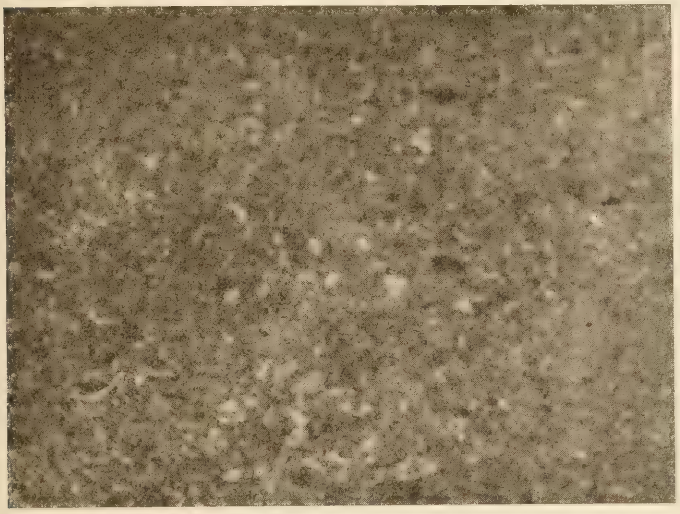
A part of the road is built upon a solid layer of salt, which is permanently protected from disintegration by a clay cut-off wall. In the construction work horses could be employed only with the greatest difficulty; all fresh water had to be hauled for many miles, and for several miles the roadbed was completely submerged in brine for months at a time. Excavating machinery of a new design was necessary to handle the material from beneath the salt beds to its place in the embankment.

CONDITION OF THE OHIO POST ROAD AFTER 10 YEARS UNDER TRAFFIC

A SURVEY MADE FOR THE DIVISION OF TESTS, UNITED STATES BUREAU OF PUBLIC ROADS

Reported by F. H. JACKSON, Engineer of Tests

ONE OF the first concrete pavements of any considerable length to be constructed in the United States was laid in 1914 and 1915 on a section of the old National Road between Zanesville, Ohio, and the Moscow bridge over the South Fork of the Licking River, a distance of about 24 miles. The pavement, built under the joint supervision of the State of Ohio and the United States Bureau of Public Roads and known as the Ohio Post Road, has now been under traffic for more than 10 years and is still in good condition.



The present condition of the Ohio Post Road is generally good. There is no scaling and only a moderate amount of surface wear

Fortunately there is available a detailed record of the materials and methods used in the construction and there is the possibility, so often lacking, of studying the present condition in the light of the conditions obtaining during construction. With this possibility in view the road was inspected for the Bureau of Public Roads in November, 1924, and observations made at that time are recorded in this article.

One condition that stands out very clearly is the greater amount of cracking that has occurred in parts of the pavement in which uncrushed gravel was used as the coarse aggregate in comparison with other parts in which the aggregate was crushed limestone. There were about twice as many full transverse cracks per mile in the gravel as in the limestone concrete sections.

Another noticeable condition is the entire absence of scaling, which the writer attributes to the fact, as evidenced by the records, that the sand was exceptionally clean, the mix dry and the finishing moderate. So excellent is the surface in this respect, and so strong the indications of the records that the result is due to the construction conditions mentioned, that the writer feels justified in saying that more careful attention to these details should go far toward eliminating scaling on new construction.

The observations also add to the evidence which is piling up from similar investigations in many parts of the country that there is an intimate relation between the extent of cracking in concrete pavements and the character of the soil immediately below the pavement. In the Ohio Post Road, as in the Columbia Pike in Virginia,[1] and other roads which have been the subject of recent reports, the greatest amount of cracking has occurred on soils of high clay content.

GENERAL DESCRIPTION OF THE ROADS

Ten of the 24 miles were surfaced with 1: 1½: 3 concrete using the uncrushed gravel aggregate, the remaining 14 miles with 1: 1¾: 3 concrete in which the aggregate was crushed limestone. Throughout its entire length the pavement is 16 feet wide and the slab, which is 8 inches thick at the center and 6 inches at the edges, rests on a flat subgrade. Contraction joints were spaced 30 feet apart and were skewed at an angle of 15° with the center line of the road. One thickness of two-ply tar paper was used in the joints except for a few miles on which ¼-inch premolded expansion joints were tried.

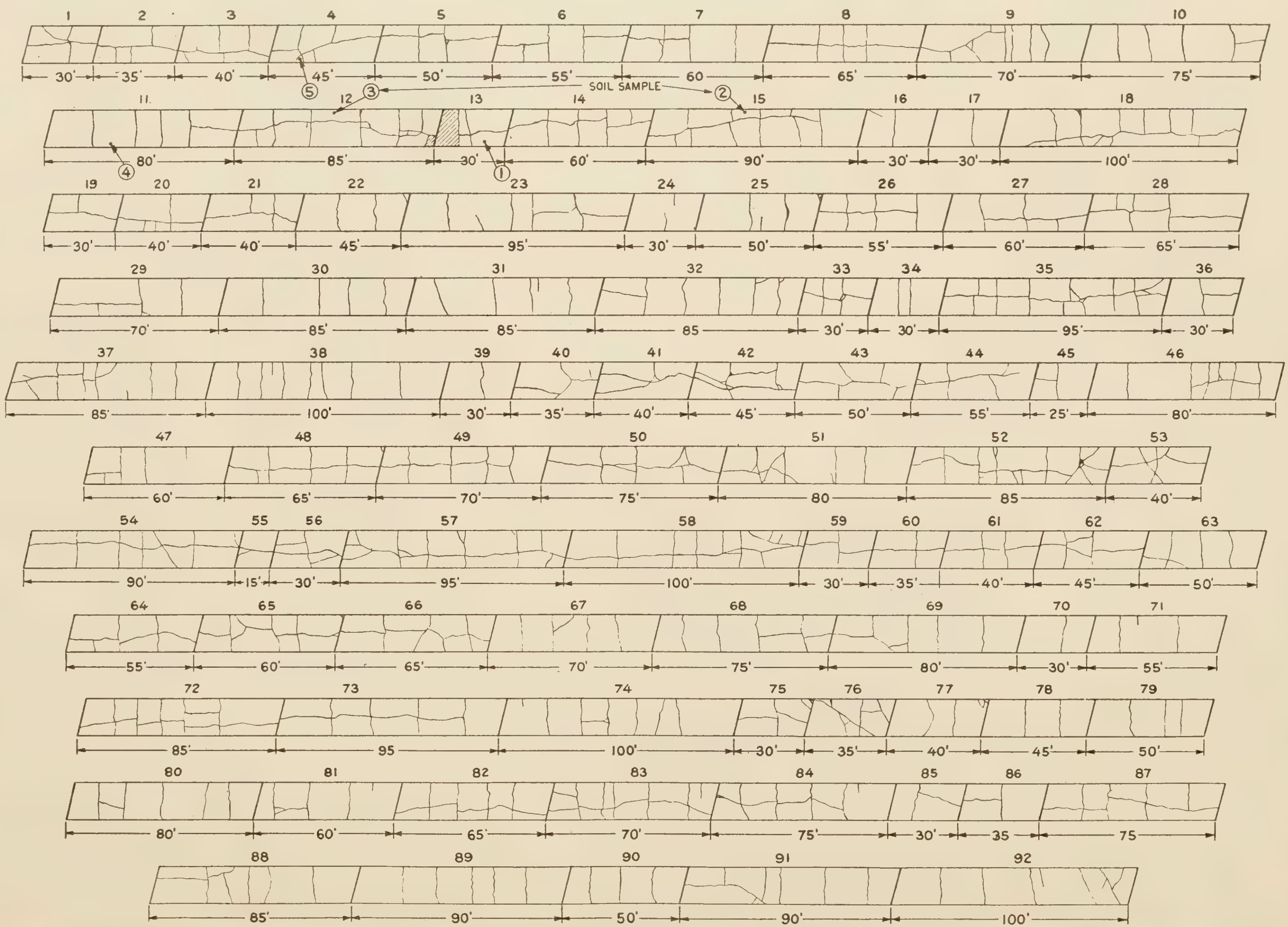
The macadam surface over which the concrete was laid had received practically no attention for a number of years prior to the improvement so that it was in a very poor state of repair. In many places the stone had disappeared entirely and during wet seasons, sections of the road became almost impassable. With few exceptions the line of the survey for the improvement followed the center line of the old road, and in no case was the departure greater than 10 or 15 feet.

Pavement in excellent condition. Longitudinal cracks show a negligible amount of vertical faulting

The maximum grade of the improved road is 7 per cent. The soil of the region which the road traverses consists for the most part of a heavy red clay with here and there an admixture of blue pipe clay which is very difficult to drain. The topography is rather rugged, affording good natural drainage for the most part, there being only about 1¾ miles at the extreme western end of the improvement—a practically level stretch—in which this condition does not obtain.

[1] See PUBLIC ROADS, vol. 5, No. 8, October, 1924.

CRACKS IN GRAVEL CONCRETE



NOTE:- FIGURES ABOVE AND AT CENTER OF EACH SECTION INDICATE NUMBER OF SECTION. FIGURES BELOW AND AT CENTER OF EACH SECTION INDICATE LENGTH OF SECTION IN FEET. SHADED AREAS INDICATE BITUMINOUS CONCRETE REPLACEMENT

FIG. 1.—Crack survey of experimental section of Ohio Post Road in Muskingum County. This section was surfaced with 1:1½:3 gravel concrete. The cracks noted were present in the pavement on Nov. 10, 1924.

CRACKS IN LIMESTONE CONCRETE

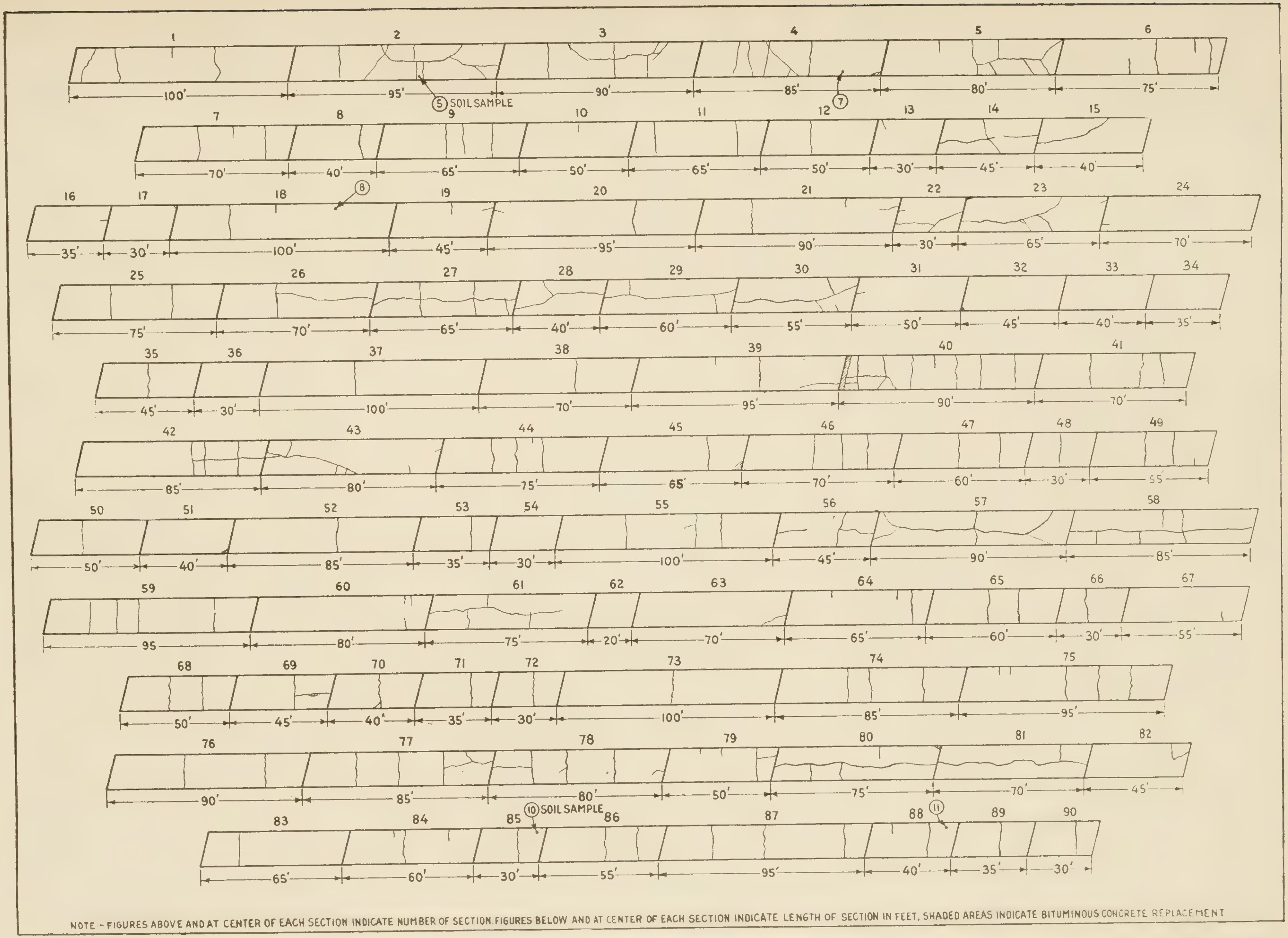


FIG. 2.—Crack survey of experimental section of Ohio Post Road in Licking County. This section was surfaced with 1:1¾:3 limestone concrete. The cracks noted were present in the pavement on Nov. 10, 1924.

MATERIALS AND CONSTRUCTION METHODS

Records of the physical tests made on the Portland cement used indicate that it passed all of the usual requirements.

The sand, obtained from a washing plant at Dresden, Ohio, was exceptionally well graded and clean, as indicated by the results of the typical analyses and tests shown in Table 1. In view of the following description of the surface appearance of the pavement to-day, it is of interest to note that the maximum silt content shown by any of these analyses was 2.6 per cent, and that the maximum passing a 100-mesh sieve was 4 per cent. In only one of the eight analyses reported was the silt content greater than 1.3 per cent.

As previously stated, both uncrushed gravel and crushed limestone were used as coarse aggregates. The gravel was obtained from the same source as the sand and was of good quality. The limestone, also of excellent quality, was obtained from one of the Scioto River quarries near Columbus, with the exception of that used in about 4,500 feet of the pavement, which was obtained from a local quarry. The characteristics of both materials are indicated in Table 2.

The water, pumped from streams crossed by the road, was also of good quality.

TABLE 1.—*Results of tests of sand*

Sample No.	Mechanical analysis—Total retained on sieve number							Silt
	10	20	30	40	50	80	100	
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1	18	34	49	63	84	97	98	0.7
2	16	33	52	69	91	99	99	0.3
3	8	21	44	64	88	97	98	1.3
4	14	26	47	62	81	93	96	0.5
5	10	22	42	60	88	99	99	0.0
6	4	19	45	68	89	96	98	0.5
7	17	41	65	78	91	96	98	1.3
8	19	41	62	74	88	95	97	2.6

TABLE 2.—*Results of tests of coarse aggregate*

Sample No.	Material	Mechanical analysis—total retained on screens					Wear	Toughness	Hardness
		1½-inch	1-inch	¾-inch	½-inch	¼-inch			
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1	Limestone.	9	44	73	96	100			
2	do	3	59	80	97	100			
3	do		13	51	90	100			
4	do						3.4	8	16.7
5	do						3.2	5	15.8
6	do						3.3	12	18.5
7	do						3.9	15	17.6
8	Gravel		5	31	72	92			
9	do		24	45	73	96			
10	do		4	15	37	82			
11	do	1	6	17	49	96			
12	do		6	17	50	86			

All materials were conveyed from the railroad sidings to the job by means of an industrial railway constructed along the right of way. Aggregates were stored on the subgrade and were proportioned by means of wheelbarrows of such size that the desired quantities were secured by striking off the materials level with the tops. The concrete was mixed in one-half cubic yard paving mixers of the boom-and-bucket type, and in general the mixers were so operated that each batch of concrete remained in the drum at least 45 seconds. Great care was exercised to regulate the consistency of the mix so that the concrete would hold its shape after being placed, struck off, and finished. All reports on file indicate that more than usual attention was given to this feature, and that the concrete was, if anything, too dry rather than too wet. This point is also of interest in view of the present condition of the pavement. The concrete was struck off by means of a wooden strike board and tamped with a steel templet 6 inches wide and shaped to conform to the surface.

The work of finishing the surface proceeded immediately after the tamping and was accomplished by means of wooden floats of two sizes; one about 8 feet long, operated by two men, and the other about 2 feet long, operated by one man. The long float was operated from two bridges and was shoved back and forth longitudinally across the pavement. The short one was for final finishing. For the most part the surface was brought to final finish not more than 50 feet behind the mixer. Although the finish was good, there was no attempt to secure a surface of exceptional smoothness, such as is frequently made in current practice. There was consequently little tendency toward overfinishing. Thus, it is noted that three of the factors which from time to time have been brought forward as causing surface scaling, viz, excessive fine material in the sand, wet mix, and overfinishing, were conspicuously absent on this job.

A canvas cover was spread over the surface of the concrete as soon after it was finished as possible. From 15 to 24 hours after laying, the canvas was removed and a 2-inch earth covering was placed and kept continuously wet for a period of two weeks, after which it was removed and the road opened to traffic.

Typical results of compressive tests of concrete cylinders taken from time to time during the progress of the work are shown in Table 3. It will be noted that the crushing strength at 14 days of the 6 by 6 inch cylinders of both kinds of concrete ranged from about 2,400 to about 3,400 pounds per square inch. The average strength of both the gravel and the limestone concrete at 14 days was approximately 2,800 pounds per square inch.

TABLE 3.—*Crushing strength of stone and gravel concrete*

Specimens: 6 by 6 inch cylinders.
Age: 14 days (10 days under damp earth).

Set	Crushing strength of 1:1½:3 gravel concrete	Crushing strength of 1:1¾:3 limestone concrete	Set	Crushing strength of 1:1½:3 gravel concrete	Crushing strength of 1:1¾:3 limestone concrete
	Pounds per square inch	*Pounds per square inch*		*Pounds per square inch*	*Pounds per square inch*
1	3,280	3,430	5	2,855	2,935
	3,170	3,060		2,745	3,210
		3,840			3,250
2	2,440	2,660	6	2,320	[1] 3,070
	2,450	2,770		2,650	[1] 3,180
	2,520	2,760		2,820	[1] 3,430
3	2,395	2,415	7	2,760	[1] 2,790
	2,550	2,335		2,995	[1] 3,160
	2,270	2,390		2,925	[1] 3,275
4	3,350	2,390	8	3,120	
	3,120	2,440		2,620	
	3,620			3,490	

[1] Specimens 28 days old and 14 days under damp earth.

RELATIVE CRACKING OF GRAVEL AND LIMESTONE CONCRETE

As the same sand and cement and the same details of construction were used throughout, the possibility of comparing the behavior of the two kinds of concrete was anticipated when the road was built, and two special experimental sections were laid. The sections were so located as to have practically identical traffic, subsoil, and drainage conditions. Both were constructed through gently rolling country; each contained approximately the same amount of pavement through cut and on fill; and each was constructed with contraction joints varying from 30 to 100 feet apart, the distance changing by increments of 5 feet and repeating for a distance of approximately 1 mile in each case. All the conditions on these two experimental sections being so nearly alike with the exception of the kind of coarse aggregate it is interesting to compare the relative amount of transverse cracking which has taken place in them during the 10 years since they were constructed, and with this in mind a detailed crack survey was made at the time of the recent inspection.

The results of the crack survey are reproduced in Figures 1 and 2. It will be seen at once that many more cracks appear in the uncrushed gravel section than on the crushed limestone section. The relative amount of cracking may be determined in a number of ways. For instance, by counting the actual number of concrete slabs formed by the cracks and joints on each section and dividing into the total area of the section, we obtain the average area of concrete slab in each section after the 10 years of service. Calculated in this way, we find that the average area of the concrete slabs as they exist to-day on the gravel section is 137 square feet, whereas the average area of the slabs on the limestone section is 320 square feet—about two and one-half times greater. Comparison of the two sections likewise shows that, whereas on the gravel section every one of the original slabs has cracked at least once, on the limestone section there are 11 slabs still intact. One of these is 20 feet long; four are 30 feet long, two, 35 feet long; two, 40 feet long; one, 45 feet long; and one, 50 feet long. There are 230 full transverse cracks on the gravel section and 107 on the limestone section. The full transverse or contraction cracks on the gravel concrete section average 24 feet apart as against 54 feet on the limestone concrete section.

Inasmuch as soil, drainage, and traffic conditions are practically identical, it would appear that the difference in cracking was due to some characteristic of the concrete itself. As previously stated, a slightly richer mix was used in the gravel concrete—i. e., 1 : 1½ : 3 as against 1 : 1¾ : 3 for the limestone concrete—but all other factors remained exactly the same, with the exception of the coarse aggregate. It is fair to assume, therefore, that the difference in the cracking of these two sections is due to the character of the coarse aggregate used. Results of typical compression tests of the concrete made on specimens cast at the time of construction are given in Table 3. It will be noted that there is very little difference in the crushing strength of the two classes of concrete. Unfortunately, there are no transverse tests of the concrete available, but it is possible that the difference in cracking is due to the high tensile strength of the limestone concrete.

RELATION OF CRACKING TO CHARACTER OF SUBGRADE SOIL

During the course of the inspection, 10 samples of subgrade soil were obtained from beneath the edges of the pavement—5 on the crushed limestone section and 5 on the uncrushed gravel section. Certain of these samples were taken at points where extensive cracking had taken place and others on sections which had cracked very little. The results of physical tests of the samples are given in Table 4, and the exact locations from which they were taken are indicated on Figures 1 and 2. The figures in circles on these charts indicate the numbers of the soil samples.

TABLE 4.—*Results of physical tests of subgrade soils*

Sample No.	Relative amount of cracking in concrete [1]	Classification of soil	Mechanical analysis: Material in original sample retained on 10-mesh sieve	Mechanical analysis: Material passing 10-mesh sieve: Sand	Silt	Clay	Moisture equivalent	Capillary moisture	Volumetric shrinkage	Dye adsorption No.
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
1	Large	Clayey silt	5	15	43	42	20	30	17	23
2	do	Silty clay	9	11	42	47	19	29	15	19
3	do	do	8	8	26	65	22	31	23	26
4	Small	Clayey sand	18	45	19	36	15	29	20	16
5	Large	Silty clay	9	12	34	54	21	29	16	24
6	do	do	6	18	35	47	22	29	22	38
7	Small	do	7	28	35	37	18	26	18	14
8	do	do	15	16	31	53	23	37	18	23
10	do	Clayey silt	17	29	38	33	15	25	17	18
11	do	Silty clay	12	14	36	50	19	30	16	21

[1] In general the use of the term "large" indicates the presence of longitudinal cracking in addition to the usual transverse cracks, and the use of the term "small" the absence of longitudinal cracks.

The shoulders are below the edges of the pavement in places but, in general, the drainage conditions are good

Although the number of subgrade samples is too small to warrant drawing any definite conclusions, attention should be called to certain indications which seem to show that the amount of cracking may be influenced by the character of the underlying soil. For instance, the soil represented by sample No. 3, which showed a very high clay content, 65 per cent, with only 8 per cent of sand and a moisture equivalent of 22 per cent, was taken from beneath the pavement at a point where considerable cracking had taken place. The transverse cracks at this point averaged 15 feet apart with a longitudinal crack, offset slightly from the center on the side from which the sample was taken. Again, sample No. 5, carrying 54 per cent clay, 11 per cent sand, and a moisture equivalent of 21 per cent, was taken from a point under slab No. 4, which had cracked in several places. On the other hand, sample No. 4, which was taken from under the center of slab No. 11, contained only 36 per cent clay as against 45 per cent sand and a moisture equivalent of 15 per cent. At this point no longitudinal crack

(Continued on page 92)

A STABILITY TEST FOR BITUMINOUS MIXTURES[1]

DEVELOPED BY THE DIVISION OF TESTS UNITED STATES BUREAU OF PUBLIC ROADS

Reported by W. J. EMMONS, Highway Research Specialist, and B. A. ANDERTON, Chemist

THREE years ago the United States Bureau of Public Roads undertook the study of the stability of bituminous paving mixtures. The program adopted embraced both experiments upon especially constructed pavements and investigations in the laboratory using compressed specimens, the objects being to develop a test which would render possible the predetermination of the relative stability of combinations of materials and ultimately to evolve a theory of proportioning.

Late in 1922 a circular track or roadway was paved with 27 asphaltic concrete mixtures of widely varying proportions laid on a smooth concrete foundation. Traffic was applied in the form of a loaded truck, commencing in October. During the ensuing winter all of these mixtures showed no displacement, but with the advent of warm weather shoving began to occur. By the end of July reference screws set in the mixtures showed that movements had occurred in all sections, virtually imperceptible in some and amounting to several feet in others. Although this test was designed primarily to determine relative resistances of mixtures under traffic for the purpose of correlation with the desired laboratory test, it was natural to attempt to draw direct conclusions from their behavior. Such conclusions, however, were confusing and evidently inconsistent.

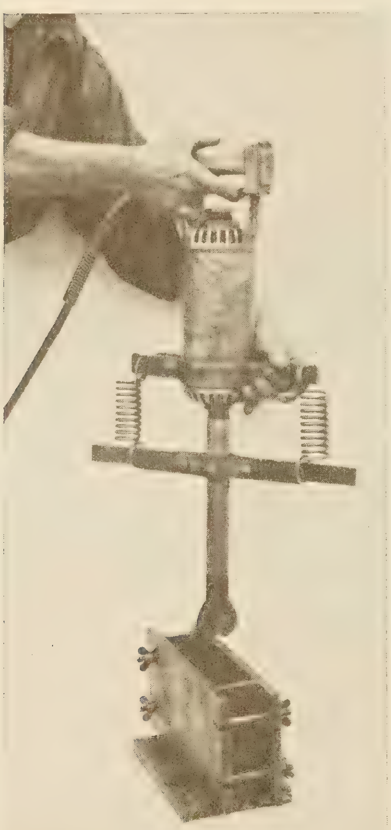


FIG. 1.—Mold and tamping apparatus for use in forming specimens

During the winter of 1923–24 sawed specimens of these mixtures were subjected to compression tests and laboratory investigations were made upon the component sand mortars and coarse aggregates. Results of the latter in connection with the observed action of the track indicated the essential importance of developing the factors influencing the behavior of sand mixtures independently of the presence of the coarse particles. Therefore, in July, 1924, the asphaltic concrete sections were removed and in their place a second series was constructed. This time 33 sections were laid, of which 5 were asphaltic concretes and 28 were sheet asphalts, the customary intermediate binder course under the latter being omitted. Following the installation of measuring devices and thermocouples, traffic was started about the 1st of September and, after being suspended during the winter months, has now been resumed. Several of the mixtures have already been displaced to some extent and it is anticipated that marked differences in their respective resistances to displacement will be shown by all of the sections before the warm months have passed.

LABORATORY TEST DEVELOPED

Meanwhile, considerable has been accomplished in the way of developing a laboratory test by means of which it is hoped to reproduce in terms of laboratory results the demonstrated relative stabilities of the service test mixtures. A test has been developed which differentiates between mixtures of varying composition, and although it is as yet in somewhat tentative form it appears decidedly promising. Results indicate that it is probably applicable to mixtures of both fine and coarse graded types. The test involves the molding of a rectangular slab of the mixture and, by pressure exerted on one side of the confined specimen, extruding a certain portion through openings in the sides and bottom of the mold. Specimens used in this test are 8 inches long, 6 inches high, and 2¼ inches thick. The mixtures are prepared by hand or mechanical mixing and are compressed in a collapsible steel mold, the sides of which are slightly greased. Compression is obtained by means of an electric hammer to which a square-ended tamper is fitted. The hammer being used works on the electromagnetic principle and strikes about 1,500 blows per minute. As the heated composition is fed in small increments, the mold is gradually filled and finally struck off to a level surface by means of a hot iron. Five to eight minutes are required to mold a specimen by this method. Figure 1 shows the apparatus used in the process of forming a specimen.

Although sheet asphalt mixtures can be molded into specimens under gradually applied pressures as imposed by a testing machine, it has been found that adequate compression can not be obtained in the case of asphaltic concretes without fracturing the stone particles. With the trap-rock aggregates used in the tests thus far, this method of tamping has resulted in very little breaking of the aggregate, even when the voids in the specimens made have been low.

The strength or resistance to displacement as measured by the several methods of testing attempted is largely dependent upon the density to which the specimens are compressed. Consequently, at some time previous to testing, the compacted specimen is removed from its mold and its specific gravity determined. From the known specific gravities and the proportions of the constituent materials the percentage of voids in a specimen is calculated.

DISPLACEMENT CAUSED BY SHEARING FORCES

It is apparent that the force which results in the longitudinal displacement of the bituminous surface is a shearing force. When the mixture is compressed under the roller the aggregate particles occupy certain

[1] Presented at meeting of American Society for Testing Materials, held at Atlantic City, June 22-24, 1925.

positions with relation to each other, and in combination with the bituminous binder possess to a greater or less degree strength to resist the forces which tend to change this structure. If, under conditions affecting the plasticity of the mixture, forces are applied of sufficient magnitude the aggregate particles move over one another and occupy new positions, giving rise to a different internal structure which may be less strong than the original. With greatly reduced strength waving will ensue, or, under a condition of extreme plasticity, rutting may result. Such a mixture must be regarded as unstable under the traffic, climatic, and other local conditions to which it may have been subjected.

It is felt, therefore, that the proper test for stability should be essentially one of shear and that the force applied should in some manner cause an internal movement and rearrangement of the particles without leaving them free to dissociate themselves completely during the progress of the test. The expedient of subjecting to pressure a specimen confined in a mold and forcing it through a single restricted orifice seems to fulfill these conditions and appears to be quite satisfactory for the testing of fine-graded mixtures. Considerable experimentation with such a single opening has already been made by other investigators, using varied sand aggregates and fine mixtures. It is felt, however, that this method is not likely to prove successful for use with mixtures containing coarse aggregate since, in specimens of a reasonable size, the forced rearrangement of the original position of the coarse fragments will result merely in the formation of a new and articial internal structure with arching of the particles over the orifice, rendering a determination of the original resistance impossible.

The test here described is intended to be applicable to the entire range of aggregate sizes, and minimizes the objectionable arching action by permitting individual fragments considerable latitude in direction of movement.

DESCRIPTION OF THE TEST

The testing form or mold provides three openings for the extrusion of the mixture, the center 4 inches of the bottom and the lower 3 inches at each end. Figure 2 illustrates the construction of the testing mold and its position upon bearing plates during the application of the load. The testing mold is identical with that used in forming the specimen except that full height end plates are necessarily used during that process.

Subsequent to the determination of the specific gravity of the specimen, it is confined in the testing mold and immersed in a water bath maintained at 60° C. A generous time has thus far been allowed to raise the specimen to this temperature, but it is probable that an immersion period of 4 hours is sufficient. The selection of 60° C. as the testing temperature was

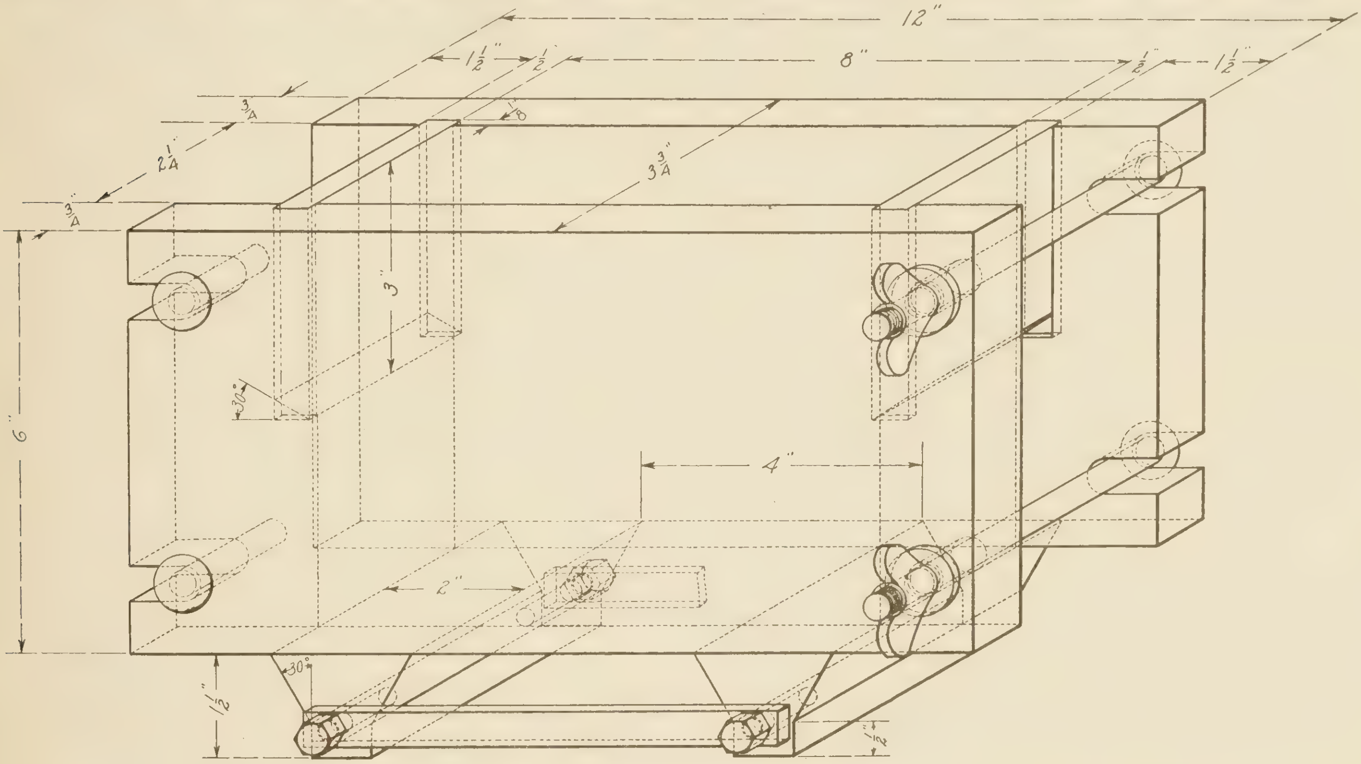


FIG. 2.—Diagram of testing mold and base plates

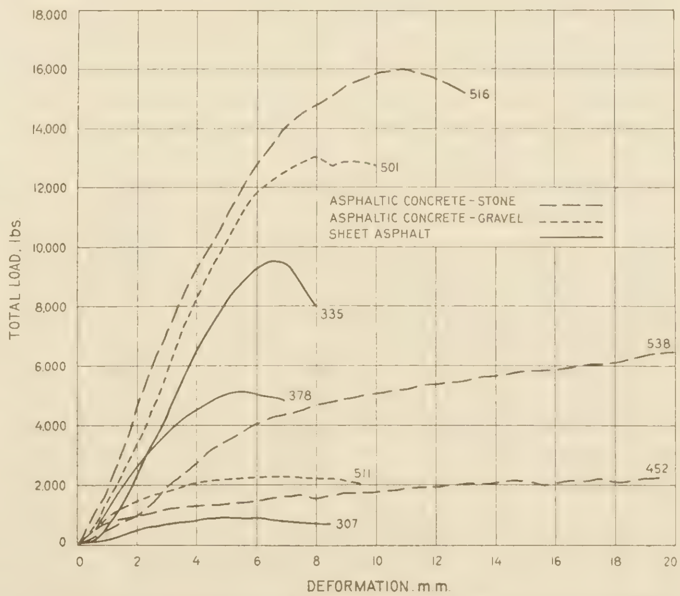


FIG. 3.—Typical stress-deformation curves of asphaltic concrete and sheet asphalt specimens

FIG. 4.—Specimens of asphaltic concrete and sheet asphalt after testing

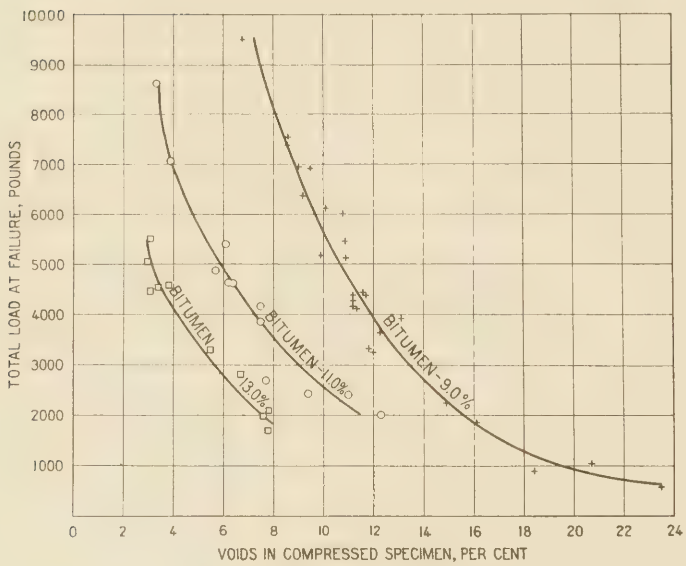


FIG. 5.—Relation between percentage of voids and strength of sheet asphalt containing three percentages of bitumen

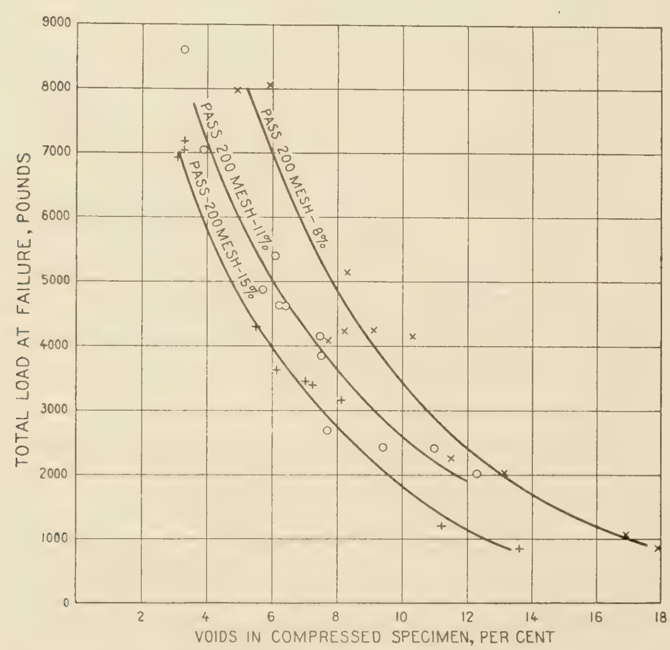


FIG. 6.—Relation between percentage of voids and strength of sheet asphalt containing three percentages of filler

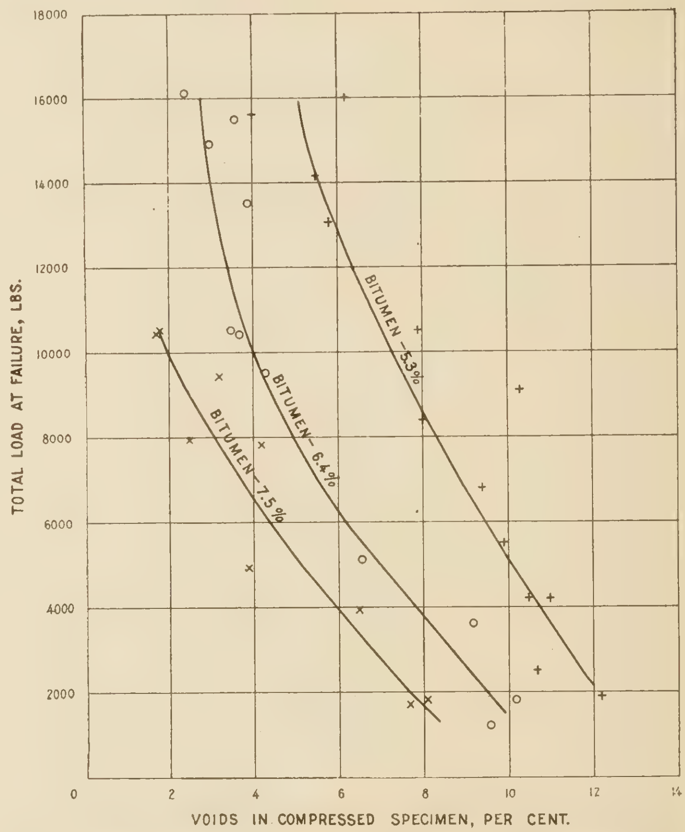


FIG. 7.—Relation between percentage of voids and strength of stone asphaltic concrete with three percentages of bitumen

made as the result of thermocouple measurements of temperatures in the service test pavements. This temperature was reached during extremely hot periods when, of course, the pavement mixtures were also most susceptible to displacement.

When ready for testing the mold containing the specimen is placed upon the properly spaced base plates in a metal tank containing water at 60° C., which is in turn placed upon the weighing table of a 20,000-pound compression machine. The load is applied through a spherical bearing block which rests upon a steel plate having a one-sixteenth inch clearance around the sides of the mold. The machine is run at its slowest testing speed, which with this machine lowers the head at the rate of 0.073 inch per minute. The loads are observed at 0.5-millimeter intervals of deformation.

RELATION BETWEEN STRENGTH AND VOIDS IN BITUMINOUS MIXES

Figure 3 shows typical stress-deformation curves resulting from tests of both sheet asphalt and asphaltic concrete mixtures. In all tests of the former type a very definite maximum load is reached, after which deformation of the specimen progresses under a decreasing load. This statement is also true of the asphaltic concrete mixtures tested thus far, provided that in the process of molding a specimen a good density is obtained. Specimens of this type which are not well compressed frequently do not exhibit definite points of failure, although indications evidenced by periods of continued deformation under constant load are often noted. This situation, however, is not likely to prove disturbing, since it is improbable that much useful information can be obtained from specimens which are not compressed to densities comparable with those attained in construction work. Poorly compressed specimens were, however, purposely made to determine the limits of usefulness of the test being developed. In Figure 3, specimens 452 and 538 were poorly compressed; specimen 516 was molded to a high density. The differences in behavior due to these conditions are clearly shown by the shapes of the curves.

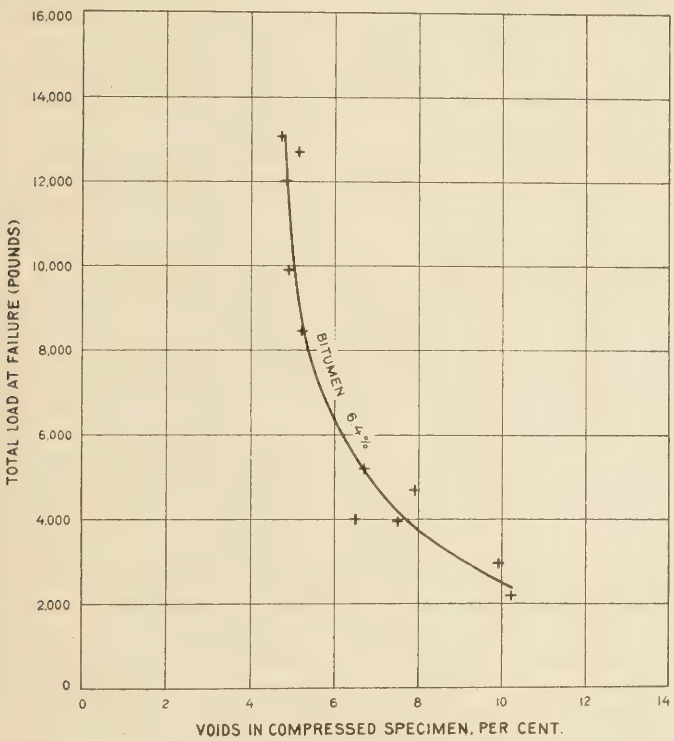


FIG. 8.—Relation between percentage of voids and strength of gravel asphaltic concrete

Figure 4 illustrates the condition of tested specimens after they are removed from the testing molds. They are shown here in an inverted position. The center specimen is composed of a sheet asphalt mixture, while the end ones are of asphaltic concrete. In the vicinity of the mold orifices the internal structure of the tested specimens is entirely disrupted; and when the test is carried as far as was done in the case of the specimen shown at the left, the extruded material crumbles readily. No fracture of coarse aggregate resulting from deformation under test has been noted in the extruded material.

Figures 5, 6, 7, and 8 show the relation between voids in a large number of the specimens and their respective maximum strengths, or, in the case of the lower-density asphaltic concrete specimens, the load at which the form of the stress-deformation curve seems to indicate a reduced stability. The proportions used in these mixtures were varied in such manner as to indicate the sensitivity of the test. A Potomac River sand possessing a grading commonly regarded as suitable for light-traffic sheet asphalt construction was used in all these specimens. Limestone dust served as a filler and a Mexican petroleum asphaltic cement of 55 penetration was used throughout the work. Trap rock graded from 1½ inches to one-fourth inch, but containing a considerable number of fragments whose greatest dimension was 2 inches, was used in the stone asphaltic concrete. Gravel graded between the same limits constituted the coarse aggregate in the series of tests whose results appear in Figure 8.

Figures 5 and 6 indicate differences in the strength of the sheet asphalt mixtures resulting from changes in the bitumen and filler contents, respectively. Figure 7 shows the effect of variations in bitumen content upon a certain asphaltic concrete. In these latter mixtures the bitumen contents were computed by assuming that the stone required 1.25 per cent of bitumen and that the sand and dust carried 9, 11, and 13 per cent of bitumen in the three series indicated as containing 5.3, 6.4, and 7.5 per cent of bitumen, respectively, thus conforming to the percentages used in the three sheet asphalts shown in the curves of Figure 5. The total aggregate mixture of the asphaltic concrete specimens is composed of equal parts retained upon and passing a 10-mesh sieve. The specimens of the single series of gravel asphaltic concrete are of the same proportions as the stone asphaltic concretes of Figure 7, which contain 6.4 per cent bitumen.

These results should not be taken as definite measures of the stability of mixtures so proportioned. Data thus far obtained are much too meager to be so used, and the correlation between the behavior of the service-test sections previously referred to and the results of the strength tests remains to be accomplished before definite interpretation of the results can be given and the true value of the test confidently asserted.

TABLET COMMEMORATES VISIT OF LATIN AMERICANS

A bronze tablet commemorating the visit to the United States of delegates to the Pan American Highway Commission was unveiled at the Pan American Union in Washington on June 16.

In presenting the tablet Ambassador Mathieu of Chile said: "It is intended to express the deep appreciation and gratitude of the delegates from the republics of Latin America for the many courtesies and kindnesses shown them in the United States, and especially for the inspiration and stimulus which they derived from their visit to this great country. The inspection which they made not only convinced them of the marvelous progress of road building in the United States but also kindled their enthusiasm to foster similar movements in their respective countries.

EFFECT OF GRADING ON SAND STRENGTH RATIOS

BY THE DIVISION OF TESTS, UNITED STATES BUREAU OF PUBLIC ROADS

Reported by C. E. PROUDLEY, Assistant Engineer of Tests

THE quality of concrete sand has been determined by means of the strength ratio test for a number of years, in some cases by means of compression tests, but more frequently by means of tension tests. It has been noticed, however, that the two methods do not agree for determining the quality of the same sample of sand. The discrepancy has been so great in some instances as to make it possible for a sand to meet requirements for quality when tested by one method and fail if the other method is used.

The continued occurrence of such discrepancies has led to a study of the data available in the physical laboratory of the Bureau of Public Roads for the purpose of finding the factors influencing the relationship between the two methods. The first study which is described in this article embraces the relation between quality and grading as it exists for a large variety of sands which have been used or proposed for use in concrete. There is no thought, as a result of this study, of establishing either method as most suitable for indicating quality. Each method has its advantages and one test is probably as suitable as the other.

The most noteworthy observations to be drawn from this analysis are that coarse grading of sand results in an increase of the compressive strength ratio as compared to the tensile strength ratio and in general the tensile strength ratio test is more favorable to sand than the compressive strength ratio.

The data for the comparisons were obtained from routine tests made in the laboratory during the past three years. In all there were about 180 materials represented, most of which were considered satisfactory for concrete work, and some of which were doubtful. All were natural sands and covered a complete range of common types.

Reference to American Society for Testing Materials Standard C9–21, Section XIV, will give a description of the method of making, storing, and testing the tension specimens. Tentative standard method C9–16T, of the American Society for Testing Materials, describes the making of compression tests, which is essentially the same as performed in this laboratory. It should be noted here that the consistency of the natural sand mortar was made as nearly the same as that of the Ottawa sand mortar as the operator could judge by close observation and feeling. Inasmuch as five operators took part in this series of tests, it is probable that the influence of the personal factor is comparatively small.

For the purposes of this investigation, it was thought best to average the 7 and 28 day strength ratios and use these figures as the quality factor of the sand. The ratio of the tensile strength factor to the compressive strength factor was next computed, in order that those materials having the same relationship of quality factors could be grouped. This means that the materials having higher tensile strength ratios than compressive strength ratios were put in one group, those having approximately the same strength ratios in another group, and so on. The mechanical analyses of each of these groups were averaged, thereby obtaining the figures shown in Table 1.

These relationships are shown graphically in Figure 1 by plotting the grading number for each sample, which is the summation of the percentages retained on the 10, 20, 30, 50 and 100-mesh sieves against the ratio of the tensile strength ratio to the compressive strength ratio. The average curve drawn on this plot was obtained by averaging the ratios in vertical columns and drawing a smooth curve through these points. This gives the average relationship between tensile and compressive strength ratios for any given grading number. The wide dispersion of the points makes this curve of little practical use other than to indicate the probable ratio of tensile strength ratio to compressive strength ratio. It is interesting to note that the average variation of this relationship from the curve is 14 per cent.

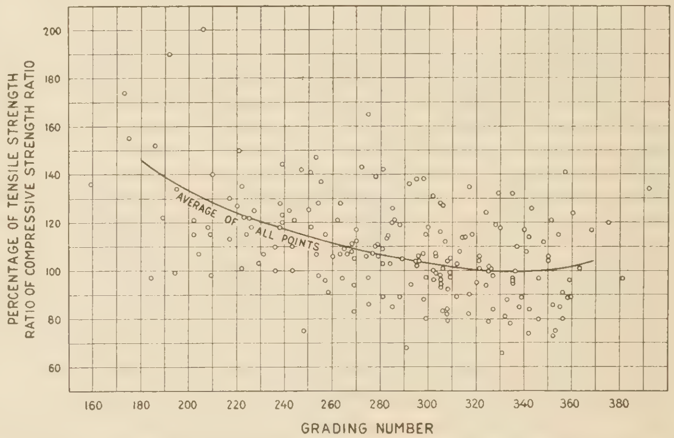


FIG. 1.—The average curve shows that an increase in the coarse grading of the sand results in an increase of the compressive strength ratio as compared to the tensile strength ratio.

Undoubtedly much of this variation is due to improper manipulation of the compression tests for none of the operators had had extensive experience in molding the 2 by 4 inch cylinders prior to these tests. Other factors likely to cause the dispersion of points noted are the shape of the sand grains, organic matter, and structural weakness of the grains. None of these factors can be accurately measured at present and consequently no attempt has been made to consider their influence. The use of sand from any one source graded artificially and used in a series of tests of this nature would eliminate nearly all of the incidental variables encountered in this study.

TABLE 1.—*Effect of grading of sand upon the relation between the tensile and compressive strength ratios*

Ratio of tensile strength ratio to compressive strength ratio	Number of samples averaged	Mechanical analysis						
		Retained on sieve No.						Loss by elutriation
		10	20	30	50	100	200	
Per cent		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
75– 85	20	22	45	67	89	96	98	2.1
86– 95	20	20	42	67	90	96	98	2.0
96–105	37	15	38	65	88	96	98	2.2
106–115	42	13	32	57	86	96	98	2.2
116–125	26	12	30	55	84	95	98	2.0
126–135	14	17	34	58	86	96	98	1.9
136–145	13	10	27	53	81	94	97	2.7

Not many laboratories are so situated that only a single source of sand need be considered. There are usually from 4 to 25 different materials available, each of which may show changes in character as they are placed on the market. The variations shown here, therefore, would prevail to a greater or lesser degree in nearly all localities. In other words, the conditions of general relationship shown on the chart are applicable in the majority of testing laboratories which operate over an extended area.

Inspection of the table shows that in those instances where the tensile strength ratio is lower than the compressive the sands average coarser in grading than where the tensile strength ratio is the higher. This is shown also on the chart. The low grading numbers indicate fine grading and at this end of the curve the ratio numbers are high—that is, the tensile strength ratio greatly exceeds the compressive strength ratio in amount.

Also it is to be noted that the average curve drops to about the 100 per cent line, where tensile and compressive strength ratios are equal, and then curves upward. This is equivalent to saying that the tensile strength probably will not fall below the compressive strength ratio. The reversal of direction of the curve is probably due to several coarse sands with higher percentages of voids than the others. It seems that in molding briquettes of exceptionally coarse sands more attention is given to the compaction of the mortar than in the molding of cylinders. The result is a denser and consequently stronger briquette and therefore a more favorable tensile strength ratio.

NEW MOTION PICTURE RELEASES OF THE BUREAU OF PUBLIC ROADS

TWO new motion pictures of road building have been prepared for the Bureau of Public Roads by the Office of Motion Pictures, United States Department of Agriculture, and these are now ready for distribution. Both show the economic and scenic values of the roads in the National forests in the Pacific Northwest and the State of California.

"The Road Goes Through" is a picture of National forest road construction, although the settings are of such a scenic nature that the subject matter would be of interest to any audience. Some of the views are: Crescent Lake in Washington—a trout fisherman's paradise; a bridge over a glacial torrent on Mount Rainier; highway engineers surveying the Coast Highway along the cliffs in Oregon; road crews at work on the Mount Hood Loop road in Oregon; teams excavating in the big tree section of California; a surveyor felling a big timber and a donkey engine clearing right of way in the "blow-down" area of the Olympic Peninsula, Wash. Gyratory rock crushers, motor trucks, road planers, blasting crews, wheel scrapers, road camps, steam shovels, and other equipment may be seen in actual use and always in a rugged and spectacular background. The picture throbs with life and will be of interest to any group regardless of age or occupation.

"Roads from Surf to Summit" has a background which is entirely scenic and gives some conception to the prospective automobile tourist of the economic resources and the hidden scenic treasures in this country. Mount Rainier, Wash., is seen with its snow capped head touching the clouds at an elevation of 14,408 feet above sea level. There are views of the Coast Highway along the rugged, rocky, and precipitous coast of Oregon, and of Mount Hood, probably the most accessible major peak in this country. The 173-mile loop road around Mount Hood has been made possible by the completion of a 37½-mile section of forest road on the southerly slope of this mountain. The road reaches an altitude of 4,735 feet above sea level and the traveler returns to Portland over the paved Columbia River Highway through the river's gorge in the Cascade Mountains.

A description of the bureau motion pictures now ready for release follows:

NEW PICTURES.

Roads from Surf to Summit.—1 reel (872 feet).

Economic resources and scenic wonders of the national forests of the Pacific Coast States now revealed to the motorists by means of modern highways constructed under the direction of the Bureau of Public Roads. Includes Lake Crescent in the Olympic National Forest, the big timber, Mount Hood, Mount Rainier, Mount Baker, Mount Shuksan, and many other natural resources and wonders of the West.

The Road Goes Through.—1 reel (911 feet).

How the western road builder overcomes barriers to transportation and builds the modern roads of our national forest and Federal-aid highway systems.

FOREST ROADS.

Roads to Wonderland.—1 reel (851 feet).

Scenic spots reached by roads that are being built by the Federal, State, and county governments; Mount Hood, in the Mount Hood National Forest; Crater Lake, in Crater Lake National Park; and Yosemite National Park. Of general interest.

Highroads and Skyroads.—1 reel (907 feet).

Building Government roads through the national forests; obstacles overcome and scenic beauties reached. Of general interest.

Around the West by Forest Roads.—1 reel (985 feet).

Examples of forest roads built by the Bureau of Public Roads in Colorado, Oregon, California, and Arizona. Of general interest.

Building Forest Roads.—1 reel (959 feet).

Men and machinery at work in the national forests, pushing good highways through the great mountains and woodlands. Of general interest.

ROAD BUILDING.

Modern Concrete Road Construction.—1 reel (995 feet).

Approved methods of highway building by the use of concrete; some of the modern machinery and practices used in this work; a contrast is drawn between old-fashioned mud roads and modern highways; the film ends with a race between a railway train and a motor truck on a concrete road. Of general technical interest.

Mixed Asphalt Pavements.—1 reel (892 feet).

Construction of asphaltic concrete and sheet asphalt roads as approved by the Bureau of Public Roads in administering the Federal-aid road act, from asphalt plant to finished road. Of general technical interest.

Building Bituminous Roads.—1 reel (772 feet).

How Uncle Sam, as the world's greatest road builder, constructs surface-treated and penetration macadam roads. The introductory scenes show sources of bituminous materials and laboratory tests to determine quality. Of general interest.

Brick—From Clay to Pavement.—1 reel (960 feet).

The progress of clay through the plant until it is laid on the road as vitrified paving brick; some finished brick roads. Of general technical interest.

What About Macadam?—1 reel (836 feet).

Approved methods of building macadam highways on Federal-aid projects. The introductory scenes explain why macadam roads may not be satisfactory for automobile traffic, and how to make them so. Of general technical interest.

Granite Block Paving.—1 reel (706 feet).

From the quarry to the finished pavement in large cities. Of general technical interest.

Tests for Better Roads.—1 reel (926 feet).

Tests conducted by the Bureau of Public Roads to determine the durability of road building materials; some of the unusual machinery used in making the tests. Of general technical interest.

The general public may obtain the films by written application to the Office of Motion Pictures, Extension Service, United States Department of Agriculture, Washington, D. C. Films are furnished free except for the transportation charges both ways. In all cases it is necessary that a reliable person assume responsibility for such charges as well as for the safe keeping, proper use, and prompt return of the films. Applications should be made as far in advance as possible and should specify preferably several alternative choices of subjects and periods of time. Schedules of proposed showings or other definite information indicating the prospective use should accompany the application. About one-half the available prints are on slow burning stock and this is being used for all new films. All films are of standard width.

(Continued from page 85)

had developed, and the transverse cracks were from 10 to 20 feet apart. All of these samples were taken from the subgrade in Muskingum County.

Turning now to Licking County, we find that sample No. 6 was taken from a section where a longitudinal crack had formed and where two transverse cracks extending partly across the pavement had developed only a few feet apart. This sample, as will be noted by reference to the table, shows a clay content of 47 per cent, a sand content of 18 per cent, and a moisture equivalent of 22 per cent. It will also be noted that the dye adsorption of 38 on this soil was the highest of any of the samples tested. The other four samples taken from Licking County were obtained at locations where little cracking had developed. Two of these samples, Nos. 7 and 10, show relatively low clay content and moisture equivalent, with corresponding high sand content. The other two, however, show high clay content and low sand content. In the last-mentioned cases, however, samples Nos. 8 and 11, it will be seen that both samples contained a considerable amount of coarse material (gravel), which may possibly have increased the stability of the soil, and reduced the amount of cracking. It will be noted also that in the case of all four of the samples from Licking County taken from under the concrete which had not cracked extensively, the percentage of shrinkage of the soil as determined by laboratory test was lower than in the case of sample No. 6. In general, it may be said that the results of the soil tests appear to bear a distinct relation to the amount of cracking in the concrete.

PRACTICALLY NO SCALING OF SURFACE

The road is practically free from surface scaling due, in the writer's opinion, first, to the fact that the sand used in the concrete contained very little fine material; second, to the fact the concrete was mixed dry; and third, that there was no tendency to overfinish the surface. Experience has demonstrated that scaling is very apt to occur on pavements which have been overfinished in an effort to secure an exceptionally smooth surface and that this condition is exaggerated when the concrete is wet and when the fine aggregate contains a relatively large amount of silt. Some surface wear, however, has taken place on the pavement. This wear is uniform across the road and has taken place to about the same extent on both the uncrushed gravel and crushed-limestone concrete. The total amount of wear which has taken place in 10 years of service, as near as can be estimated, is about one-eighth of an inch. The wear, however, has not been accompanied by an undue amount of spalling or disintegration of the concrete. This applies to the small slabs which have been formed by the excessive cracking of the gravel concrete and as well as to the edges of exposed joints or cracks. In only a very few cases has it been necessary to replace slabs due to the breaking up of the concrete and this again is a tribute to the quality of the concrete. From present indications, the pavement should be good for many years' service, assuming that proper maintenance is given the joints and cracks.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

ANNUAL REPORT

Report of the Chief of the Bureau of Public Roads, 1924.

DEPARTMENT BULLETINS

No. 105. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136. Highway Bonds. 20c.
220. Road Models.
257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314. Methods for the Examination of Bituminous Road Materials. 10c.
*347. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370. The Results of Physical Tests of Road-Building Rock. 15c.
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387. Public Road Mileage and Revenues in the Southern States, 1914.
388. Public Road Mileage and Revenues in the New England States, 1914.
390. Public Road Mileage in the United States, 1914. A Summary.
*393. Economic Surveys of County Highway Improvement. 35c.
407. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
*463. Earth, Sand-Clay, and Gravel Roads. 15c.
*532. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
*583. Report on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*586. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1916. 10c.
*660. Highway Cost Keeping. 10c.
*670. The Results of Physical Tests of Road-Building Rock in 1916 and 1917. 5c.
*691. Typical Specifications for Bituminous Road Materials. 10c.
*704. Typical Specifications for Nonbituminous Road Materials. 5c.
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*1077. Portland Cement Concrete Roads. 15c.
*1132. The Results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.
No. 1216. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
1259. Standard Specifications for Steel Highway Bridges, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
1279. Rural Highway Mileage, Incomes and Expenditures, 1921 and 1922.

DEPARTMENT CIRCULAR

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FARMERS' BULLETINS

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*505. Benefits of Improved Roads. 5c.

SEPARATE REPRINTS FROM THE YEARBOOK

No. *727. Design of Public Roads. 5c.
*739. Federal Aid to Highways, 1917. 5c.
*849. Roads. 5c.

OFFICE OF PUBLIC ROADS BULLETIN

No. *45. Data for Use in Designing Culverts and Short-span Bridges. (1913.) 15c.

OFFICE OF THE SECRETARY CIRCULARS

No. 49. Motor Vehicle Registrations and Revenues, 1914.
59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
63. State Highway Mileage and Expenditures to January 1, 1916.
*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
161. Rules and Regulations of the Secretary of Agriculture for Carrying out the Federal Highway Act and Amendments Thereto.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D-2. Effect of Controllable Variables Upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 20, D-4. Apparatus for Measuring the Wear of Concrete Roads.
Vol. 5, No. 24, D-6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 10, No. 7, D-13. Toughness of Bituminous Aggregates.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

MAY 31, 1925

GOVERNMENT PRINTING OFFICE

STATES	FISCAL YEARS 1917-1924: PROJECTS COMPLETED PRIOR TO JULY 1, 1924			FISCAL YEAR 1925: PROJECTS COMPLETED SINCE JUNE 30, 1924			FISCAL YEAR 1925: *PROJECTS UNDER CONSTRUCTION			FISCAL YEAR 1925: PROJECTS APPROVED FOR CONSTRUCTION			BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS	STATES
	TOTAL COST	FEDERAL AID	MILES	TOTAL COST	FEDERAL AID	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES		
Alabama	$ 4,598,721.63	$ 2,186,247.54	464.1	$ 1,371,376.08	$ 676,950.32	147.7	$ 15,450,912.60	$ 7,494,856.47	804.8	$	$		$ 2,436,778.67	Alabama
Arizona	8,338,365.41	4,287,683.88	527.8	978,083.89	567,297.92	78.1	2,278,241.44	1,382,630.30	149.8	449,594.93	293,904.22	46.6	2,020,355.68	Arizona
Arkansas	11,094,751.31	4,424,345.63	944.4	2,142,283.34	919,258.39	98.9	7,063,606.29	3,055,965.83	387.9	313,994.94	124,097.83	16.7	1,802,896.32	Arkansas
California	12,999,075.03	5,647,148.17	533.7	8,878,662.25	4,795,835.51	341.6	9,499,195.59	4,573,905.00	243.9	66,685.30	39,173.75	0.2	4,509,879.57	California
Colorado	8,108,070.31	4,029,898.97	502.6	2,485,167.72	1,327,686.59	108.3	4,700,294.22	2,494,541.04	195.9	732,123.20	279,865.34	32.2	2,801,126.06	Colorado
Connecticut	3,062,872.02	1,269,558.60	73.6	1,128,828.24	438,051.93	21.9	2,358,530.17	720,572.55	37.1				1,427,812.92	Connecticut
Delaware	3,066,832.22	1,007,714.83	72.5	1,224,727.59	488,475.82	34.6	489,503.74	213,581.10	12.3	639,364.40	244,183.75	14.1	151,199.50	Delaware
Florida	961,134.07	461,470.92	48.8	1,998,139.66	944,017.05	47.5	8,787,223.95	4,279,162.51	251,8	116,547.09	91,547.09	0.1	1,403,567.43	Florida
Georgia	17,167,373.32	7,955,805.20	1214.2	2,988,629.05	1,450,561.26	264.1	11,050,944.65	5,445,883.28	736.1	439,358.35	186,405.61	16.0	1,394,330.65	Georgia
Idaho	8,161,697.92	4,092,395.52	506.8	1,212,978.88	692,936.74	93.3	2,150,202.17	1,363,194.37	135.7	326,332.23	217,941.33	34.1	1,248,171.04	Idaho
Illinois	26,964,706.06	12,279,546.33	804.7	12,546,850.31	6,116,185.50	413.1	7,776,339.53	3,767,193.20	264.3	961,985.29	475,577.53	34.3	3,989,468.44	Illinois
Indiana	7,577,444.16	3,655,540.97	225.7	5,597,232.07	2,704,844.77	185.4	11,706,762.88	5,704,563.55	378.6	421,857.03	210,928.56	14.3	3,975,207.15	Indiana
Iowa	23,195,778.19	9,237,031.86	1682.9	4,020,893.35	1,842,654.30	290.3	5,588,867.96	2,534,660.17	391.9	2,779,997.22	1,188,376.05	137.6	2,603,810.62	Iowa
Kansas	17,084,136.48	6,043,176.80	502.7	9,140,903.95	3,625,812.15	308.1	12,757,239.68	5,443,788.88	620.0	728,033.69	201,106.21	13.7	2,059,764.96	Kansas
Kentucky	10,822,980.31	4,613,947.28	429.4	3,597,161.74	1,436,148.07	133.7	8,028,463.36	3,589,978.95	288.9	474,921.70	237,460.83	36.7	1,905,810.87	Kentucky
Louisiana	8,488,463.18	3,636,143.36	661.2	3,450,961.79	1,643,727.50	266.5	3,363,645.07	1,620,766.20	162.7	145,263.04	72,631.51	0.1	1,289,435.43	Louisiana
Maine	6,911,058.78	3,299,935.38	230.7	1,263,222.53	607,934.95	50.7	749,878.17	350,363.39	24.2	114,562.51	57,281.25	5.3	1,459,597.03	Maine
Maryland	6,760,044.42	3,213,321.78	243.2	1,307,190.18	606,526.37	49.2	1,909,803.12	807,640.52	56.7	1,393,774.91	528,956.13	86.3	128,288.20	Maryland
Massachusetts	10,191,202.02	4,105,727.22	232.8	3,540,547.27	1,259,604.71	62.9	4,871,161.33	1,355,248.12	77.3	568,395.79	153,810.00	8.5	2,135,507.95	Massachusetts
Michigan	13,434,135.07	6,060,612.23	494.5	2,472,673.22	1,110,505.92	106.0	14,963,098.54	7,078,061.87	481.8	352,277.44	171,034.19	5.7	3,684,784.79	Michigan
Minnesota	24,037,561.24	9,885,843.07	2292.0	6,378,124.65	2,852,798.97	429.2	6,490,887.55	3,127,400.00	670.8	1,587,176.37	410,000.00	83.3	1,166,527.96	Minnesota
Mississippi	7,888,193.89	3,828,941.39	655.0	2,191,938.63	1,056,444.54	148.2	8,738,641.87	4,363,065.28	482.7	220,062.43	110,031.20	7.5	1,464,750.59	Mississippi
Missouri	11,352,027.70	5,245,899.18	803.5	5,640,412.83	2,786,985.58	301.4	26,137,702.67	10,506,055.15	856.4	1,334,791.25	414,018.00	38.6	1,404,957.09	Missouri
Montana	8,867,279.16	4,384,335.12	791.4	1,289,321.25	933,188.03	130.3	1,882,291.46	1,379,095.35	165.1	1,057,077.93	600,720.40	119.9	5,217,551.10	Montana
Nebraska	7,876,337.16	3,714,691.59	1440.4	1,348,825.26	635,545.10	114.1	8,125,476.71	4,023,341.60	850.2	784,267.01	389,327.59	46.1	4,270,009.12	Nebraska
Nevada	3,460,245.52	1,853,624.98	225.6	1,446,557.71	1,228,225.07	131.4	4,836,660.07	4,081,664.43	405.8	374,257.39	328,156.54	61.4	346,725.98	Nevada
New Hampshire	3,076,750.19	1,487,867.58	171.3	1,088,937.67	498,359.29	36.8	812,945.64	391,481.51	26.0	102,182.11	50,992.79	4.1	371,887.83	New Hampshire
New Jersey	7,623,795.12	2,661,531.49	148.7	4,113,182.90	1,120,958.50	67.8	8,335,555.49	2,455,827.11	52.5	509,417.17	110,955.00	7.4	1,175,056.90	New Jersey
New Mexico	5,306,286.45	2,758,849.68	714.3	3,256,393.66	2,059,699.71	351.0	4,524,906.13	2,988,419.80	410.6	250,983.39	154,354.77	16.7	1,813,174.04	New Mexico
New York	18,862,742.49	8,257,844.44	572.7	7,568,694.12	3,102,822.01	201.6	30,368,096.49	10,680,589.16	644.3	5,711,500.00	1,498,931.25	99.3	6,825,057.14	New York
North Carolina	12,567,732.97	5,676,757.66	884.7	6,374,361.39	2,314,976.07	177.6	8,939,651.62	3,730,868.46	251.2	1,976,524.06	887,886.59	50.6	1,382,930.22	North Carolina
North Dakota	9,088,973.11	4,418,505.42	1587.9	1,707,265.90	833,931.18	325.6	2,766,616.44	1,394,255.38	391.8	597,953.78	320,630.51	65.1	2,577,032.51	North Dakota
Ohio	33,122,751.43	11,879,917.99	962.5	8,105,457.77	3,228,875.94	218.8	9,551,814.30	3,416,129.95	284.8	2,283,493.20	1,043,230.22	73.6	3,361,597.90	Ohio
Oklahoma	12,986,865.26	5,888,852.03	497.3	6,967,406.16	3,388,195.41	310.5	5,895,010.08	2,742,551.82	259.8	2,910,706.83	1,320,204.58	143.7	952,004.16	Oklahoma
Oregon	12,082,873.17	5,819,093.79	655.6	2,162,545.40	1,274,243.08	140.2	2,773,422.07	1,602,718.08	127.4	730,412.11	472,088.22	42.6	517,683.83	Oregon
Pennsylvania	36,825,248.98	14,114,694.79	729.7	5,616,297.45	1,952,029.32	110.3	27,232,590.52	7,277,609.43	469.8	10,380,760.11	2,837,639.27	200.3	1,779,766.19	Pennsylvania
Rhode Island	1,774,397.25	779,227.96	46.0	854,098.95	340,460.13	18.8	1,798,608.99	518,589.59	26.3	87,634.25	20,100.00	1.3	640,288.32	Rhode Island
South Carolina	9,016,476.73	4,124,045.22	924.4	1,822,999.07	846,189.44	280.6	6,830,945.32	2,615,520.84	402.3	266,706.71	82,996.62	15.9	1,071,342.88	South Carolina
South Dakota	8,674,597.86	4,244,636.27	989.8	3,367,308.41	1,720,478.53	447.8	6,538,945.37	3,211,410.37	904.9	923,685.61	432,198.51	101.0	324,976.32	South Dakota
Tennessee	6,805,683.35	3,313,936.07	259.6	6,983,457.63	3,418,143.70	238.3	11,932,658.52	5,345,527.55	422.3				1,570,014.68	Tennessee
Texas	42,341,998.56	16,190,624.91	3122.8	10,995,266.74	4,525,401.28	710.5	23,580,295.22	9,821,992.12	1468.8	3,649,542.26	1,449,369.15	208.3	4,152,540.54	Texas
Utah	3,304,423.75	1,895,805.92	219.0	2,714,473.61	1,750,151.47	180.6	2,948,312.94	1,998,339.44	214.3	505,962.57	375,279.38	51.4	943,363.79	Utah
Vermont	1,922,114.16	942,769.12	74.4	924,591.66	435,734.27	28.6	1,347,956.36	642,288.36	30.6				878,812.25	Vermont
Virginia	10,035,301.48	4,801,782.43	562.5	3,064,418.53	1,470,215.77	113.7	9,936,608.82	4,498,851.97	343.0	1,163,378.53	522,593.85	40.7	749,221.98	Virginia
Washington	11,384,615.67	5,290,895.45	457.0	1,842,601.60	781,098.36	66.2	2,769,626.50	1,329,400.00	120.5	652,246.53	274,000.00	16.6	1,330,271.19	Washington
West Virginia	5,489,747.95	2,365,041.53	255.6	1,853,452.91	865,251.80	71.1	4,864,235.15	2,024,363.78	137.4	2,370,340.51	903,965.53	61.7	392,804.36	West Virginia
Wisconsin	18,753,903.15	7,441,033.57	1325.3	3,001,359.02	1,452,667.68	121.0	2,764,923.54	1,320,055.36	135.5	1,496,912.73	767,955.00	78.3	4,570,047.39	Wisconsin
Wyoming	6,127,625.61	3,078,098.70	687.6	2,629,027.49	1,626,626.97	290.5	3,180,085.69	1,987,157.25	152.7	679,528.24	436,798.00	113.1	493,617.08	Wyoming
Hawaii							342,277.22	97,440.00	6.5				633,810.00	Hawaii
TOTALS	549,655,391.27	237,852,399.82	32452.9	176,655,291.47	81,754,712.97	8864.4	371,791,663.21	162,848,566.44	16416.0	53,692,572.14	20,988,704.15	2251.0	94,805,616.62	TOTALS

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost $ 91,433,196.89 Federal aid $ 40,763.046.11 Miles 3,833.4